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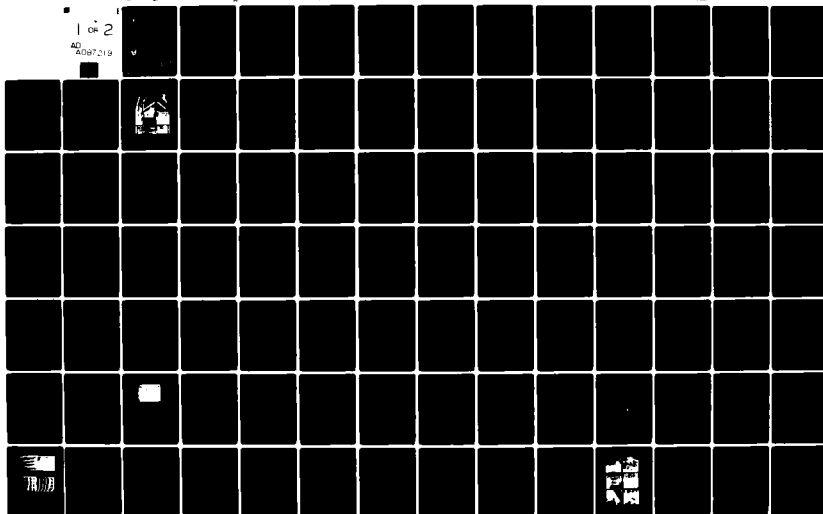
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TECHNICAL REPORT DRCPM-HEL-79-5

**MID-TERM PROGRESS REPORT ON THE
DEVELOPMENT OF ARMY CLOSED CYCLE
CIRCULATOR (CCC) SYSTEM**

Myron W. Cole
Cornellius C. Shih
High Energy Laser Laboratory

20 September 1979



U.S. ARMY MISSILE COMMAND

Redstone Arsenal, Alabama 35809

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A Closed Cycle Circulator System was developed for recirculating the laser gas through the cavity in order that problems of acoustic attenuation, thermal control, gas contamination, and power gain may be investigated for various pulsed energy inputs at the cavity. The circulator was assembled and tested for its performance evaluation. Its instrumentation subsystem was developed and calibrated to a reasonable accuracy. For safety, standard operating procedures have been established for review and approval. The instruments calibrated include hot wire anemometers for velocity and temperature.		

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piezoelectric transducers for pressure, flow meter for mass flow rate, and interferometer for medium homogeneity. A series of trial tests of the Closed Cycle Circulator System resulted in an experimental analysis of performance data providing a better control of flow conditions in the cavity through the control mechanism.

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1. INTRODUCTION

In the development of the pulsed Electric Discharge Laser (EDL), the use of Closed Cycle Circulator (CCC) for removing the heated laser gas from the cavity section has been determined to be advantageous over open cycle systems from the standpoints of run time and gas economy. However, the lack of technical data on: the characteristics and stability of fluid and thermal properties of the recirculating laser gas flow under the pulsed energy input; plasma formation; level pumping ability; shock wave attenuation capability; heat exchanger capability; gas contamination rates; and the gas reactor capability, has strongly justified the need for developing a laboratory-scale Closed Cycle Circulator at a relatively low cost to investigate the above mentioned problem areas and obtain experimental data of the circulator performance under simulated pulsed laser operations.

The program undertaken presently by Army High Energy Laboratory [1] has as its objectives to develop the Closed Cycle Circulator, to experimentally analyze the circulator performance under various pulsed energy input conditions, and to compare with theoretical analysis of the circulator performance. At the conclusion of the program, the data obtained and analyzed, as well as the knowledge and experience gained, will result in the establishment of design criteria and detailed component performance specifications for a low risk circulator system of future generation, minimizing overall weight and volume.

In the design of the circulator system, a size of the circulator was so chosen to yield scaling laws for satisfying possible system design requirements, and a hot cathode electron beam (E-beam) gun and drive were selected to provide high current density. A pulsed power supply having a 50 kV peak voltage and 1000 ampere peak current will be gated on and off synchronically with the E-beam gun allowing appropriate delay time for plasma formation of 5x5x25 cm. The laser cavity size was selected on the basis of the available discharge power capability and a possible magnitude and frequencies of acoustic waves generated in the cavity. The circulator size in length was designed to accommodate a pulse repetition rate up to 125 pps without wave interferences within the flow loop. In the final, a significant cost saving has resulted from this particular design of the circulator system due to the selections of size, configuration, bearing seal, and control system.

Through this program, the circulator system will be developed for the purpose of studying the component's requirements and technical methods of solution to the following areas of problems pertinent to the pulsed electric discharge laser technology:

- Acoustic attenuators to improve medium homogeneity to a designed level of density fractional gradient with a minimum flush factor.
- Circulator system performance in response to startup, prelasing, heat input lasing, heat removal at various flow conditions.
- Laser gas stability, composition, and contamination during the circulator operation and the verification of closed cycle pulse laser gas stability and plasma chemistry models.
- Heat exchanger requirements with respect to the medium homogeneity and pressure loss in the flow loop.
- Validation of the analytical models through computer programs for steady state and unsteady cases under pulsed energy input at various levels and repetition rates.
- Suitability of a high speed radial flow compressor for pulsed energy input operations.
- Materials evaluation and selection for components compatible with the closed cycle laser operation in the E-Beam environment and their effects.
- Compressor bearing and seal design evaluation and their improvements.
- Experiments on power gain at the laser cavity.

2. GENERAL DESCRIPTION AND SPECIFICATIONS

The Army Closed Cycle Circulator System consists of the following components [2]:

- A motor driven compressor to circulate gas in a closed duct system for electrical discharge laser experiments.
- A diverter valve and bypass to permit varying the gas flow in the main part of the duct system. The diverter valve consists of linked flapper valves in the main part of the duct system and in the bypass. These are arranged to operate in opposite ways so that as the flapper in the main duct closes the flapper in the bypass opens and less of the gas flows in the main duct and more in the bypass.

- A compressor exit heat exchanger to remove the heat of compression. This is a shell and tube type with gas flow through the tubes.
- A cavity inlet heat exchanger to condition the gas to the desired cavity temperature. This is also shell and tube with gas flow through the tubes.
- A compressor inlet heat exchanger to remove the heat of lasing or in the case of bypass operation, the heat of compression from the gas before the latter enters the compressor. This is also shell and tube with gas flow through the tubes.
- Ducting to connect the various units. Heating tapes are provided for the ducts.
- Bellows at the compressor inlet and exit to isolate the compressor from the thermal expansion and contraction of the ducts.
- A flowmeter to measure the gas flow.
- Honeycomb and screen to remove turbulence from the gas flow prior to entering the laser cavity.
- A laser cavity supplied by Redstone Arsenal.
- A water coolant supply including tank, centrifugal pump, relief and throttling valves for the compressor exit and inlet heat exchangers. The tank is fitted with a provision for liquid nitrogen cooling of the water.
- A pentane coolant supply including supply tank, catch tank, gear pump, relief and throttling valves for the cavity inlet heat exchanger. The supply tank is fitted with a provision for liquid nitrogen cooling of the pentane. The supply tank, pump, cavity inlet heat exchanger and lines are insulated with two-inch polyurethane foam. During the chilling operation pentane is pumped continuously through the complete loop (run tank, heat exchanger, catch tank, and returning again to the run tank). This same operating mode may be used during a lasing test, or optionally, the catch tank can be isolated from the run tank by means of the manual valve provided.
- A gas system for purging the outside face of the compressor seal during evacuation of the duct, for adding makeup gas to the system, and for applying gas pressure to the inside face of the compressor seal at startup to lift off the seal.

- A control system for starting and stopping the compressor, water pump, and pentane pump; and for controlling the positions of the diverter valve and the three heat exchanger throttling valves. An independent servo control is provided to maintain cavity pressure constant by controlling a vent valve on the duct.

- An instrumentation subsystem to measure pressures and temperatures at various locations around the duct for the purpose of operating the system to obtain cavity inlet temperatures from 200K to 300K.

- In addition to the basic instrumentation system of fifteen, there are provisions for installing six Kistler pressure transducers at various locations around the duct, for installing six hot wire anemometers of which three are upstream and three downstream of the cavity, and for installing gas sampling probes before the cavity and after the reactor.

- An E-Beam gun and power modulator for generating energy pulse input at various pulse rates and magnitudes.

- An interferometer subsystem to measure optically the medium homogeneity on an integrated base at the cavity section.

- A mass spectrometer subsystem to measure chemical compositions of the laser gas at various locations in the circulator.

- Safety provisions during the circulator operation are made by installing two gas monitors for pentane and one monitor for oxygen to detect the danger levels of respective gases for human safety and fire and explosion hazards of the building.

- Two acoustic attenuators are designed and fabricated to be installed upstream and downstream of the cavity for the purpose of attenuating acoustic waves generated by the pulsed energy input operation.

- A gas reactor or so-called catalytic converter is designed and fabricated to be installed downstream from the cavity so as to remove foreign elements from the laser gas with a designed composition.

Figures 1 and 2 present general views of the Closed Cycle Circulator System.

- T TEMPERATURE PROBE
- P PRESSURE PROBE
- S GAS SAMPLE PROBE
- A HOT WIRE ANEMOMETER
- K KISTLER PORT
- MS MASS SPECTROMETER PORT

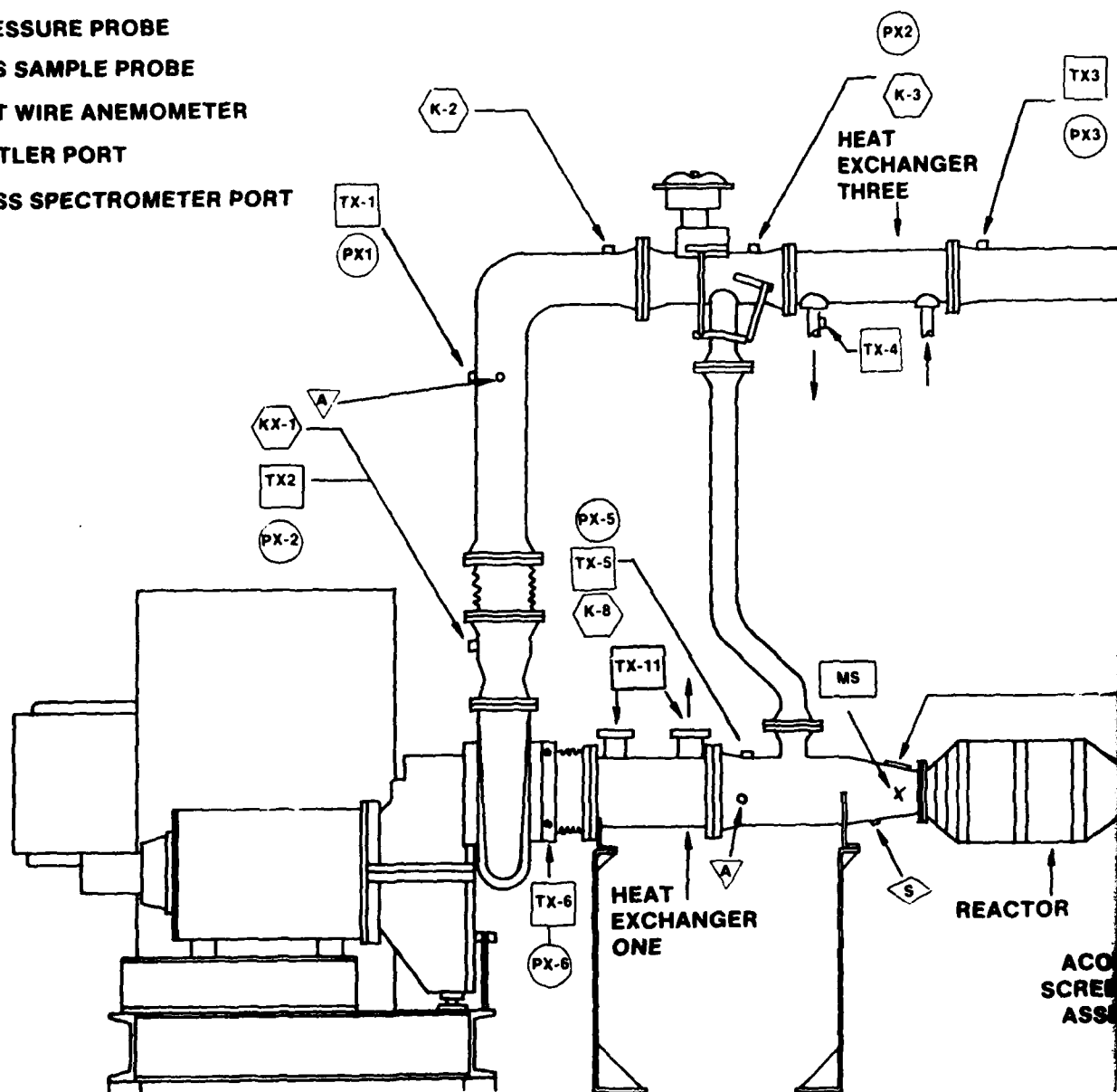
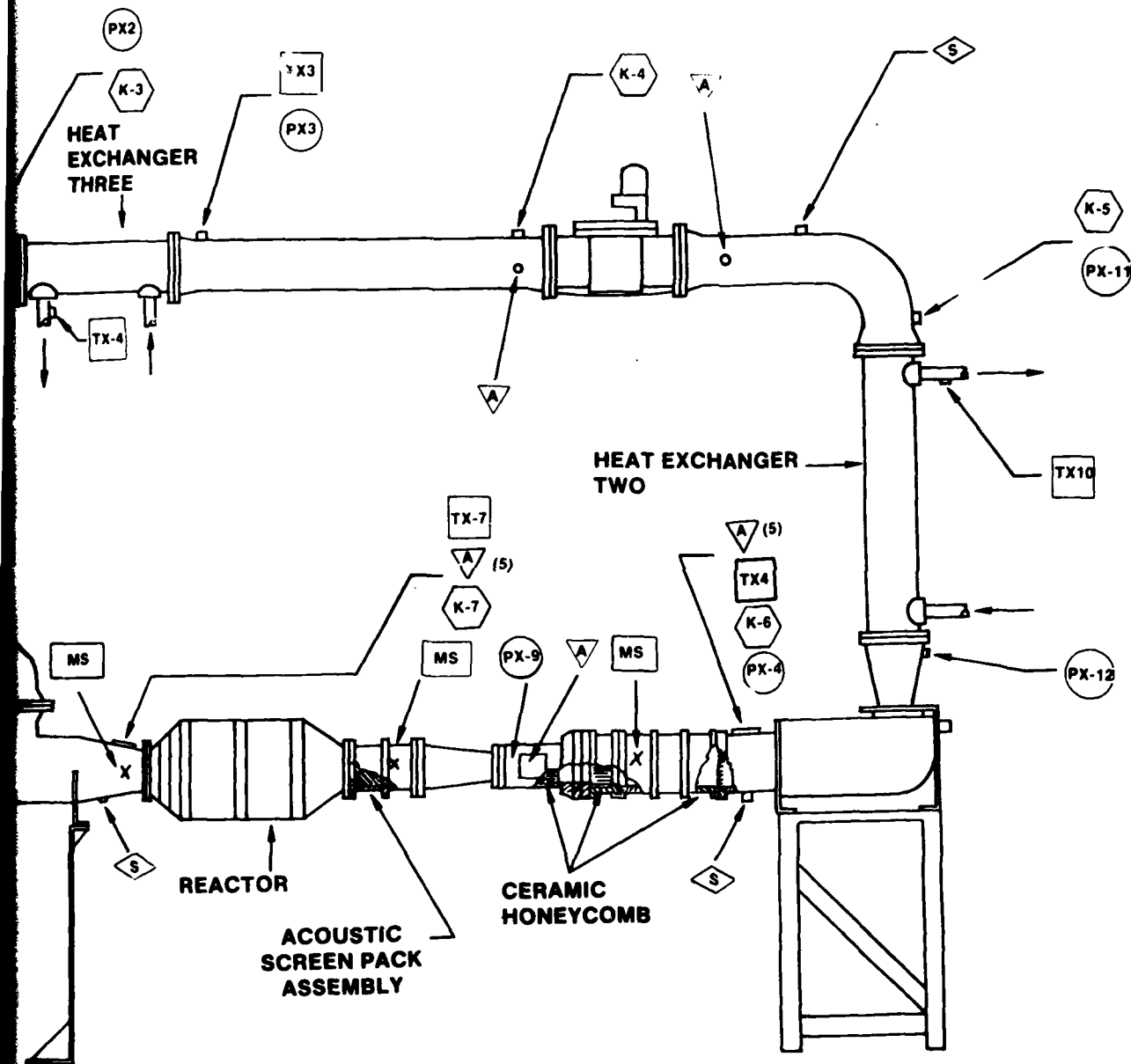


Figure 1. Schematic of Army Closed Cycle Circulator (CCC) System.



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Figure 2. General view of Army Closed Cycle Circulator System.

The circulator system characteristics and weight breakdown of the system components are listed in *Tables 1* and *2* respectively.

Specifications of the components are delineated below:

A. CIRCULATOR SYSTEM

1. **COMPRESSOR.** The single stage compressor consists of an overhung open type 19 vane impeller, inlet shroud, and 11 vane diffuser installed in a cast steel housing. The impeller is mounted directly on the high speed pinion shaft which is supported in two tilting pad bearings. The main motor drives the pinion through a gear type coupling and single step speed increaser gear supported in two sleeve bearings. The gears are of hardened steel and ground to AGMA standards. The gearbox is horizontally split in the pinion plane permitting easy inspection of the high speed bearings and removal and installation of the rotor assembly. The compressor shaft is sealed with a Crane Type 28 Kinetic Wedge gas seal for positive static sealing. A unitized fabricated steel base supports the drive motor, gear casing and compressor housing. It also forms the oil sump and contains the lubrication system for the unit. The lubrication system for the drive motor is self-contained and the gearbox lubrication is supplied by the unit system. Lube oil cooling is accomplished by a separate shell and tube oil to water heat exchanger. The unit is supplied with an electric/pneumatic control system which monitors all critical parameters and provides permissive circuits along with alarm and shutdown circuitry for safe operation of the equipment.

The specifications for the unit are as follows:

Inlet	10 inch ANSI 125 lb. flange
Outlet	6 inch ANSI 125 lb. flange
Gas 3:2:1 molar mix of H ₂ : N ₂ : CO ₂	
Molecular weight	18.8
Cp/Cv	1.48
Inlet pressure	11.4 psia
Inlet temperature	116°F
Inlet volume	2425 cfm
Outlet pressure	20.52 psia
Outlet temperature	271°F
Pressure ratio	1.8
Brake horsepower	136

TABLE 1. CLOSED-CYCLE CIRCULATOR SYSTEM CHARACTERISTICS

<u>Operating conditions</u>	
Gas composition (nominal 3:2:1 mix)	
Helium, mole percent	50.0
Nitrogen, mole percent	33.3
Carbon dioxide, mole percent	16.7
Mass flowrate, lb/sec	0.3 to 1.4
Pressure drop (maximum at 1.4 lb/sec) (psid)	
Total loop	(8.4)
Compressor exit heat exchanger	0.6
Flowmeter	0.5
Cavity inlet heat exchanger	0.43
Cavity plus acoustic attenuators	6.0
Cavity exit heat exchanger	0.36
Compressor pressure ratio (maximum)	1.8
Compressor speed (rpm)	33,000
Laser cavity inlet temperature (°K)	200 to 300
Laser cavity pressure (psia)	15
<u>Static conditions</u>	
Pressure	
Maximum (psia)	30
Minimum (microns)	500
<u>Coolant storage conditions</u>	
Water	
Capacity (gallons)	110
Pump outlet pressure (psia)	35.1
Pentane	
Capacity (lb)	110
Pressure at 180°K (psia)	100

TABLE 2. CCC SYSTEM WEIGHT BREAKDOWN

	<u>Pounds</u>
Compressor and drive	6760
Interconnect ducting (including flanges)	320
Compressor exit heat exchanger	84
Flowmeter	80
Cavity inlet heat exchanger	103
Cavity simulator	108
Cavity exit heat exchanger	92
Water supply system	105
Ethylene supply system	168
Controls	200
Motor-driven water pump	<u>100</u>
Dry weight	8120
Water	889
Ethylene	<u>142</u>
Wet weight	9151

Power	460V, 3 phase, 60 cycle
Driver speed	1780
Compressor speed	26,000

The compressor manufacturer, Turbonetics, Inc., tested the unit and reported the actual performance to be as follows:

Inlet pressure	11.4 psia
Inlet temperature	116°F
Inlet volume	2485 cfm
Pressure ratio	1.91
Horsepower	134
R (Molecular weight 18.67)	82.76

The compressor is fitted with a Crane Packing Company Type 28 gas seal. This seal consists of a stationary carbon ring and a rotating chromed stainless seal mating ring. The parts are in contact when stationary and the leakage will be less than 6 scim at a pressure differential of 15 psid with the duct and compressor evacuated.

The specified 5.6 torr cu. ft. per minute corresponds to 12.79 scim. When the mating ring rotates the stationary carbon ring lifts off slightly to eliminate rubbing contact which would cause overheating and destruction of the seal faces. In this situation the leakage will be less than 100 scim at a pressure differential of 5 psid, with the compressor discharge at 20 psia. Provisions are required for introducing a pressure differential of 5 psid (9.3 scim) to start to lift off the seal and for replacing this with discharge pressure once the compressor is operating.

An Allen Bradley Combination Starter 712-FAB282 is provided for starting the compressor motor.

2. COMPRESSOR EXIT HEAT EXCHANGER. This assembly is a Young Radiator Company shell and tube heat exchanger Model HF803-DR-1P less the end bonnets. The tubes are 3/8 inch, baffle spacing is 2 1/4 inch, and the coolant makes one pass. The specifications for the unit are as follows:

Inlet and Outlet	
Flange OD	11 inch
Flange ID	8 inch
Bolt Circle	16-1/2 inch bolts on a 9 3/4 inch bolt circle

Length	28 1/8 inch
Gas 3:2:1 molar mix of $H_2:N_2:CO_2$	
Molecular weight	18.7
Gas flow	1.4 lbs/sec
Inlet pressure	20.1 psia
Inlet temperature	741° R
Pressure drop	.6 psid
Outlet temperature	576° R
Coolant:	

Water flowing at 4.0 lbs/sec and inlet conditions of 19.7 psia and 540° R. Pressure drop 5 psid and outlet temperature 560° R.

Heat removal	79.2 BTU/sec
--------------	--------------

3. CAVITY INLET HEAT EXCHANGER. This assembly is a Young Radiator Company shell and tube heat exchanger Model HF804-DR-1P less the end bonnets. The tubes are 3/8 inch, baffle spacing is 2 1/4 inch, and the coolant makes one pass. The specifications for the unit are as follows:

Inlet and Outlet	
Flange OD	11 inch
Flange ID	8 inch
Bolt Circle	16-1/2 inch bolts on a 9 3/4 inch bolt circle
Length	37 1/8 inch
Gas 3:2:1 molar mix of $H_2:N_2:CO_2$	
Molecular Weight	18.7
Gas Flow	1.4 lbs/sec
Inlet Pressure	19.2 psia
Inlet Temperature	576° R
Pressure Drop	.6 psid
Outlet Temperature	350° R
Coolant:	

Normal pentane flowing at 3.1 lbs/sec and inlet conditions of 35 psia and 296° R. Pressure drop 14 psid and outlet temperature 350° R.

Heat Removal	105.2 BTU/sec
--------------	---------------

4. **COMPRESSOR INLET HEAT EXCHANGER.** This assembly is a Young Radiator Company shell and tube heat exchanger Model F-1002-DR-1P less the end bonnets and mounting feet. The tubes are 3/8 inch, baffle spacing is 2 1/4 inch, and the coolant makes one pass. The specifications for the unit are as follows:

Inlet and Outlet	
Flange OD	14 7/8 inch
Flange ID	10 3/8 inch
Bolt circle	16-1/2 inch bolts on a 13 3/8 bolt circle
Length	23.63 inch
Gas 3:2:1 molar mix of	
H ₂ :N ₂ : CO ₂	
Molecular Weight	18.7
Gas Flow	1.4 lbs/sec
Inlet Pressure	11.9 psia
Inlet Temperature	660° R
Pressure Drop	.6 psid
Outlet Temperature	576° R
Coolant:	

Water flowing at 2.0 lbs/sec and inlet conditions of 19.7 psia and 540° R. Pressure drop of 5 psid and outlet temperature 560° R.

Heat Removal	40.4 BTU/sec
--------------	--------------

5. **DUCTING.** The ducting connects the compressor, heat exchangers, flowmeter, and laser cavity together and provides structure to support the elements. The main portion of the duct consists of 8 inch diameter aluminum pipe and standard Flowline Corporation flanges with transitions at the compressor outlet to 6 inch diameter and at the compressor inlet to 10 inch diameter. A 4 inch bypass connects the compressor outlet to the inlet. Bellows are provided at outlet and inlet to isolate the compressor from thermal expansion and contraction of the ducts. At the cavity inlet and outlet the cross section of the duct changes to a rectangle 15 cm by 40 cm (5.91 by 15.75 inches). The cavity inlet elbow is provided with vanes, honeycomb, and a screen to reduce velocity variations in the gas to a minimum at entrance to the cavity. The cavity inlet elbow is also fitted with a manifold for the introduction of liquid nitrogen to prechill the elbow to the desired cavity inlet gas temperature. The manifold surrounds the elbow except for the section immediately preceding the cavity inlet where a removable shroud continues the manifold in order to allow access to the instrumentation in this area. The liquid

nitrogen is introduced before the elbow turn and just after the cavity inlet heat exchanger and after gasifying flows around and along the elbow to exit at the end of the elbow through the shroud just before the inlet to the cavity. The ducting is designed for a flow of 1.3 lbs/sec. of a 3:2:1 molar mixture of $H_2:N_2:CO_2$ with a pressure drop of less than 2.5 psid.

The ducting also includes a provision for extending the cavity from 60 inches to 120 inches by removing a spool piece and replacing it with another.

6. **DIVERTER VALVE.** The diverter valve was designed to provide the following angles and flows based on the analog model:

TEMP. IN CAVITY R	MAIN DUCT GAS FLOW LBS/SEC	VALVE FLAPPER ANGLE FROM CLOSED POSITION	
		MAIN DUCT	BYPASS DUCT
360	1.3	35.0°	20.3°
360	.13	8.6°	40.6°
540	1.3	60.0°	1.1°
540	.13	8.7°	40.5°

The actuator mount has been designed to mount the actuator in two positions, such that the operating angle of the flappers may be approximately halved and the sensitivity doubled when operating at the cold condition. In addition, extra length has been provided on the actuator links between the two flappers so that new holes may be drilled to provide a different relationship between the flappers.

7. **WATER SYSTEM.** The water system consists of a galvanized steel tank with a lid. The tank holds 110 gallons of water and is fitted with a dished bottom having a 1 1/2 inch female NPT. The tank outlet is connected to the 1 1/2 pump inlet. The Pacific Pumping Company Model 1250-5 centrifugal pump specifications are as follows:

Flow	50 gpm
Head	81 ft.
Pressure	35.1 psi
Driver speed	3450 rpm

Driver horsepower	2
Electrical Power	460V, 3 phase, 60 cycle

The outlet pump discharge is fitted with a 1 inch Lunkenheimer Fig S 658 relief valve set for 50 psi with a return to the tank. The discharge is also connected to the compressor exit and inlet heat exchangers through throttling shutoff valves.

The specifications for these valves are as follows:

Compressor exit heat exchanger valve

Masoneilan 1 inch Camflex Valve, Model 35-35200, Full

Trim, C, 14, Carbon Steel Body

Compressor Inlet Heat Exchanger Valve

Masoneilan 1 inch Camflex Valve, Model 35-35200,

Reduced Trim, C, 5.6, Carbon Steel Body

The discharge from the heat exchangers is piped to drain or can be recirculated to the water tank.

An Allen Bradley Combination Starter 712-AAB 242 is provided for starting the water pump motor.

8. **PENTANE SYSTEM.** The Pentane System consists of two 55 gallon stainless steel tanks, one for supply and one for catching the discharge from the heat exchanger. Each tank has a 2 inch NPT female outlet fitted with a 2 inch Goddard Valve Corporation gate valve. The tank outlets are connected to the 1 1/2 inch pump inlet. The Lobee Pump and Machinery Company Model 12 LOL gear pump specifications are as follows:

Flow (water)	22 gpm
Pressure	100 psi
Driver speed	1745 rpm
Pump speed	900
Driver horsepower	5
Electric power	460V, 3-phase, 60 cycle

The pump discharge is fitted with a 1 1/2 inch Teledyne Farris Engineering Type 1876-M relief valve set for 100 psi with a return to the supply tank. The pump discharge is connected to the cavity inlet heat exchanger through a throttling shutoff valve.

The specification for this valve is as follows:

Cavity inlet heat exchanger valve

Masoneilan 1 inch Camflex Valve, Model 35-35200,

Full Trim, C_v14, Stainless Steel Body

The discharge from the heat exchanger is piped to the catch tank. An Allen Bradley Combination Starter 712-BAB 242 is provided for starting the pentane pump motor.

9. **LIQUID NITROGEN SYSTEM.** The liquid nitrogen system requires a supply of liquid nitrogen at low pressure to the three ASCO 8222D2LT cryogenic solenoid valves.

The valves on the water tank and the pentane tank feed liquid nitrogen to immersed coils of copper tubing, vented to the atmosphere. The valve on the cavity inlet elbow discharges directly into a jacket surrounding the elbow and the gasified nitrogen flows around the elbow and exits to the atmosphere at the cavity inlet.

10. **GAS SYSTEM.** The gas system requires a supply of makeup gas at no more than 250 psi. This gas is passed through a Monnier 201-5200-6 filter and 107-5002-6 regulator which reduces the pressure to 50 psi. The gas then flows to the three branches for makeup gas, purge gas and seal gas. The specifications for these systems are as follows:

• **MAKEUP GAS SYSTEM**

Control Solenoid ASCO 8210-C94

Orifices LADISH 72111 1 inch orifice unions drilled as follows:

FLOW		ORIFICE
PERCENT OF MAIN DUCT FLOW	LBS/SEC	DIAMETER INCHES
.5	.0065	.104
1.0	.013	.147
2.0	.026	.209
3.5	.0455	.277
5.0	.065	.339

- **PURGE GAS SYSTEM**

Control solenoid ASCO 8223-A21

Orifice LADISH 72111 1/2 inch orifice union drilled as follows:

FLOW LBS/SEC.	ORIFICE DIAMETER INCHES
.000146 (5.3 SCI/sec)	1/64

- **SEAL GAS SYSTEM**

Control Solenoid ASCO 8223-A21

Orifice LADISH 72111 1/2 inch orifice union drilled as follows:

FLOW LBS/SEC	ORIFICE DIAMETER INCHES
.030 (0.62 SCF/sec)	.209

Check Valve Hoke 6211 F4B

Based on the specifications provided for the system, flow and the conditions of recirculating flows in the CCC system were analyzed and presented in *Figure 3*.

11. **CONTROL SYSTEM.** The control system for the CCGR consists of electrical and pneumatic controls assembled in a control console. An Allen Bradley H31C lock switch is provided to control the electrical power to the console. The compressor, however, can be operated with controls at the compressor if the switch on the compressor is turned to local instead of remote. The water and pentane pumps are only controlled from the console.

The compressor was procured with failsafe circuitry and instrumentation to ensure a safe automatic shutdown in the event of any of the following:

- High oil temperature
- Low oil pressure
- Low oil level

- T TEMPERATURE PROBE
 (P) PRESSURE PROBE
 (S) GAS SAMPLE PROBE
 (A) HOT WIRE ANEMOMETER
 (K) KISTLER PORT
 (MS) MASS SPECTROMETER PORT

P 20.52 psia
 T 600° R
 $\rho = 0.05951 \text{ lb/ft}^3$ Duct Flow
 V 43.155 ft/sec
 A 0.54514 ft²

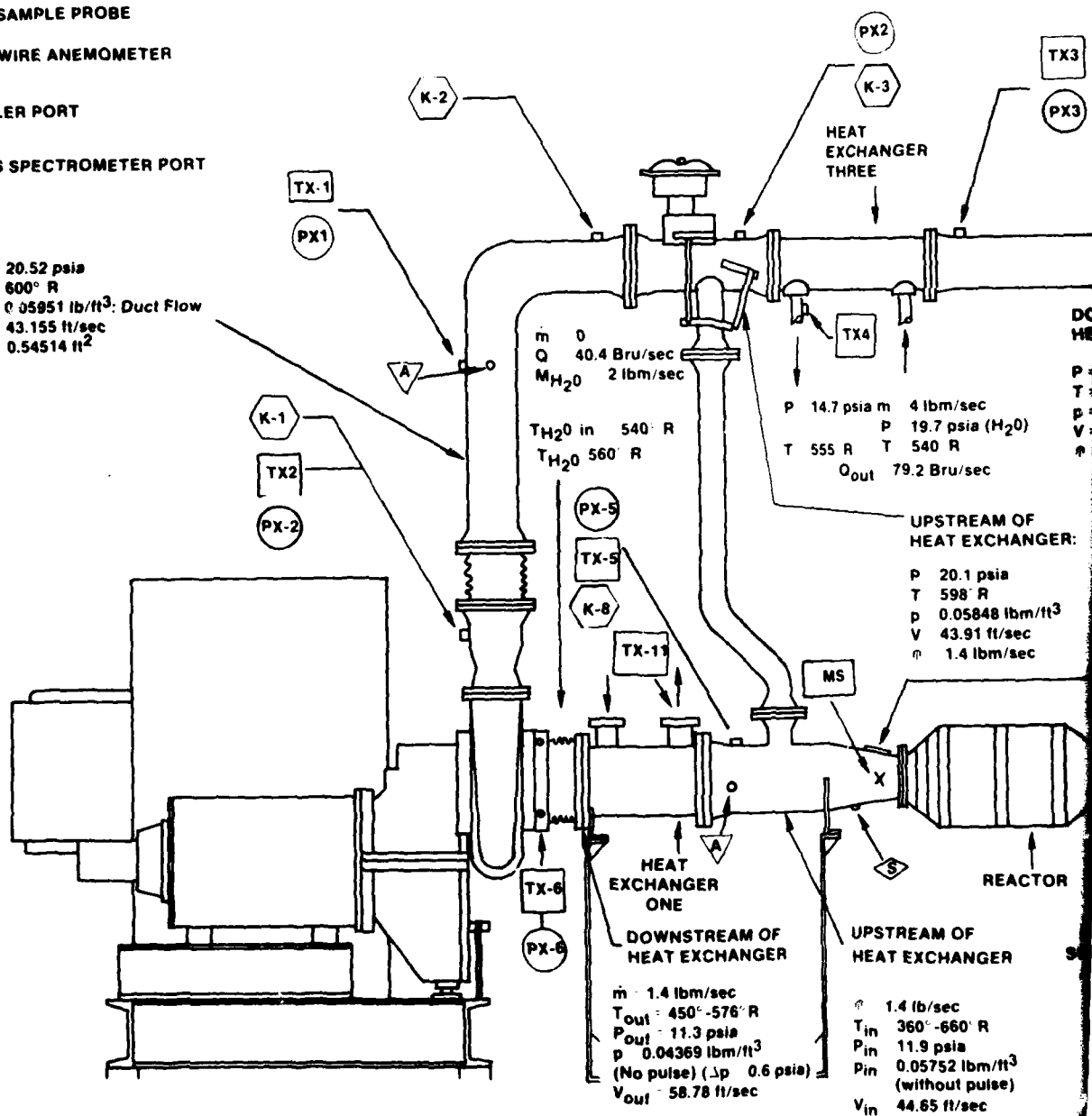
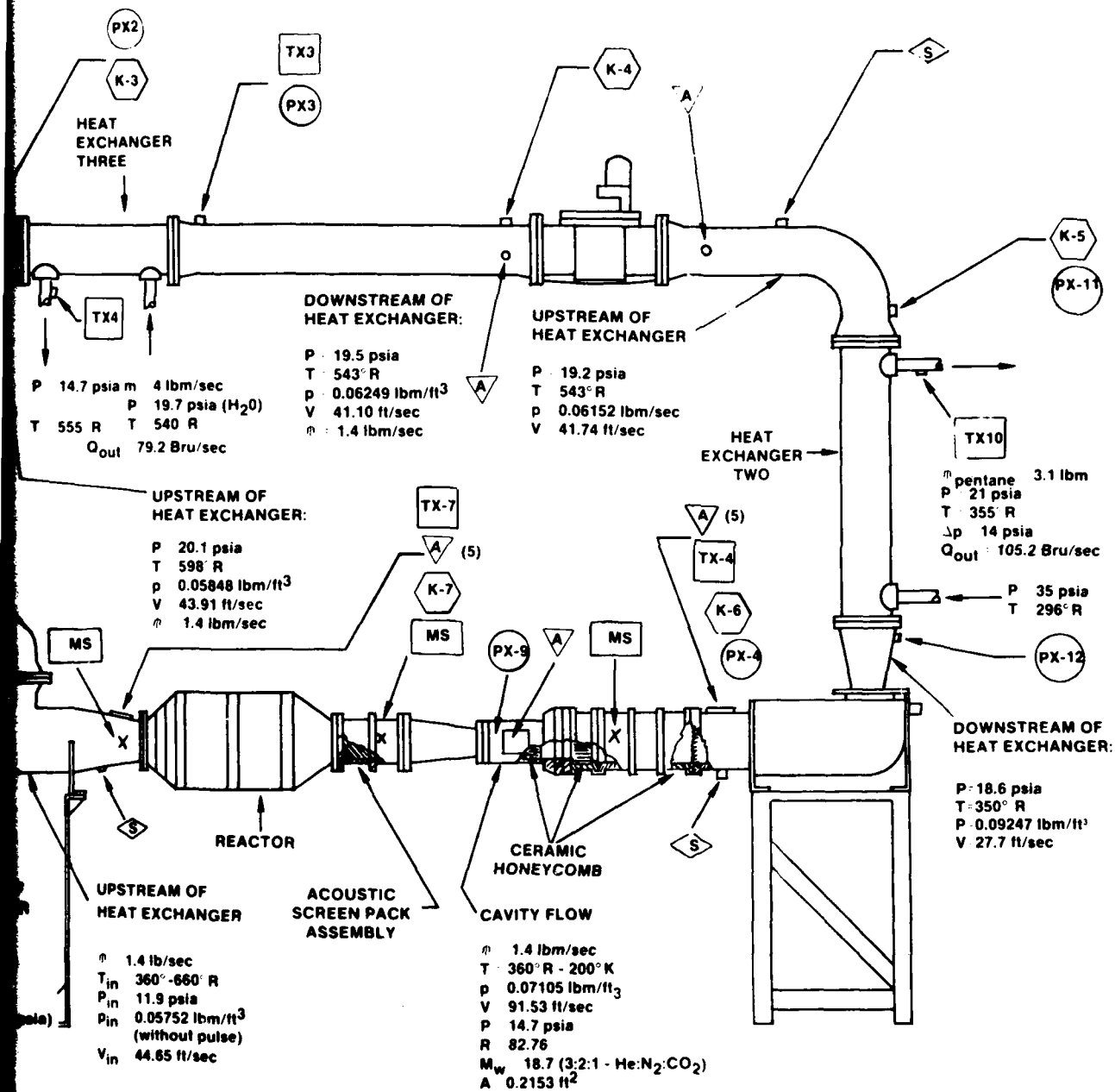


Figure 3. Flow and thermal conditions of recirculating flows in CCC system.



High discharge temperature
Low seal gas differential pressure

In addition, the compressor cannot be started if any of the following conditions exist:

Low oil temperature
Low oil level
Low seal gas differential pressure

The compressor is also provided with a surge sensor which lights the remote alarm light if surge occurs. The existence of any of the above conditions lights an identifying light at the compressor.

The CCGR control console accordingly has a minimum of controls for the compressor. These are as follows:

Compressor ready light
Allen Bradley Pilot Light 800T-P16G
Compressor alarm light
Allen Bradley Pilot Light 800T-P16R
Compressor start switch
Allen Bradley Switch 800T-A1A
Compressor operating light
Allen Bradley Pilot Light 800T-P16G
Compressor stop switch
Allen Bradley Switch 800T-B6A

The ready light signifies that the above noted conditions for starting have been met. The alarm light provides an initial warning of high oil temperature, low oil pressure, low oil level, or high discharge temperature. If the condition becomes worse, automatic shutdown occurs. In the case of low seal gas differential pressure no warning occurs before automatic shutdown. In the case of surge automatic shutdown does not occur. The alarm light on the control console lights and the light identifying the condition is lighted at the compressor control panel and remains on until the reset is pushed. In the case of low oil temperature at start the ready light on the console does not light and the identifying light on the compressor does.

The water and pentane pumps are each provided with a similar start switch, operating light, and stop switch.

The control console also incorporates Allen Bradley H17B on/off switches for the following:

- Seal gas solenoid with a 10 second timer for automatic shutoff.
- Makeup gas solenoid
- Liquid nitrogen solenoids for the water and pentane tanks and the cavity inlet elbow.

The purge gas solenoid is controlled by an Allen Bradley H31B Lock Switch mounted on the compressor.

The pneumatic portion of the control system requires an inlet gas supply at a pressure no more than 150 psi. This gas supply is introduced into a Monnier 202-2100-2 filter mounted in the console and the pressure is then reduced to 20 psi by a Monnier 101-1004-2 regulator also mounted in the console. The output pressure from the regulator is then distributed to four Monnier 101-3004-2 regulators mounted in the control panel. Operation of these regulators will apply 0 to 20 psi to the control valve actuator to which the regulator output is connected. The actuators are of the spring return type, hence the actuator motion is proportional to the pressure applied. The pressures of the four regulators are read on Haskel F60P4-2 pressure gauges. The gauges are also mounted in the panel each one above the regulator being measured. The four valves so controlled are the diverter valve of section 2.6 and the three throttling shutoff valves in the heat exchanger coolant systems of sections 2.7 and 2.8.

The 20 psi pressure is also distributed to a pneumatic servo control system for controlling cavity pressure. This consists of a Foxboro 43AP-FA4 Pneumatic Indicating Controller, which senses cavity pressure and controls a vent valve with positioner.

The specification for this valve is as follows:

Vent Valve

Masoneilan 1 inch Camflex Valve, Model 35-35200, Full
Trim, Cv 14, Carbon Steel Body with 7600 Positioner (Linear)

B. INSTRUMENTATION SYSTEM

1. INSTRUMENTATION SUBSYSTEM FOR THE CIRCULATOR OPERATION.

The instrumentation system is a Hy-Cal Engineering Model CSD-948-A. The Model CSD-

- Pressure signal conditioners (PX1 through PX9) 9
- Range of pressure inputs (PX2, PX7 and PX8) 0 to 3877 TORR
- Accuracy of pressure (Including sensor and digital indicator) ± 26.7 TORR
- Range of pressure inputs (PX1, PX3, PX4, PX5, PX6 and PX9) 0 to 3877 TORR
- Accuracy of pressure (Including sensor and digital indicator) ± 6.2 TORR
- Analog recorder output (pressure) 1 mV/TORR
- Flow signal conditioner (FX1) 0 to 25.0 meters/sec
- Accuracy of flow input (4 to 20 mA input) $\pm 1\%$ of SPAN
- Analog recorder output (flow) 100 mV/meter/sec
- Input power 117 VAC 50/60 Hz

Although the readout portion of the flowmeter system is included in the the above instrumentation system, the turbine meter itself and its direct reading totalizer with flow rate option were procured separately. The turbine meter is a Daniel Industries, Inc., 8 inch, 125 lb. CWP Electro Magnetic Gas Turbine Meter having the following specifications:

- Operating pressure max 125 psi
- Flanges DRILLED TO MATCH 150 psi ANSI

• Maximum flow SCFH* at 25 psi	161800
• Minimum flow SCFH* at 25 psi	4927
• Pulses/actual cubic foot	24
• Pulses/actual cubic meter	847
• Frequency at max flow Hz	400

The direct reading totalizer with flow rate option is a Daniel Industries, Inc., 2239-1112 Direct Reading Totalizer, having the following specifications:

TURBINE METER INPUTS

- **Type**
DC coupled for nominal 14 V square wave or pulse
- **Input threshold**
 - Positive going waveform: +7 V
 - Negative going waveform: +5 V
- **Open circuit input terminal voltage**
+6 V
- **Input resistance**
20 K Ω , dc to 400 Hz; decreasing to 9 K Ω at 3 kHz and above
- **Frequency range**
 - Totalizer:
0 to 4 kHz
 - Rate:
10 Hz to 4 kHz

*14.73 psia, 60°F, .6 SP.GR.

TURBINE METER OUTPUTS (FLOWRATE)

- **Type**
 - Voltage
0 to 10 V, 5 mA maximum load
 - Current
4 to 20 mA, 950 Ω maximum load.
Zero and span of current output internally adjustable
 ± 25 percent of full scale with respect to the rate meter and the 0 to 10 V output.
- **Electrical**
 - Ripple
< 2 mV rms at 32 Hz
 - Response time
0 to 90 percent, 1 sec., maximum
 - Linearity
0.1 percent of full scale (32 Hz to 1 kHz range)
0.25 percent of full scale (1 kHz to 4 kHz range)
 - Average temperature coefficient
< 0.15 percent/ $^{\circ}$ F over operating range when
calibrated at 1 kHz as full scale.

As noted in the discussion of the Hy-Cal Engineering system, the 4 to 20 mA signal from the direct reading totalizer is connected to the input of the system. This is scaled so that 20 mA is equivalent to 102556 actual cubic feet per hour or 25 meters per second flowing in a duct having a 7.98 inch inner diameter.

2. INSTRUMENTATION SUBSYSTEM FOR TIME-DEPENDENT MEASUREMENTS OF VELOCITY, PRESSURE AND TEMPERATURE IN THE CIRCULATOR.

• **PRESSURE MEASUREMENT.** The instrument used for pressure measurements is a battery of four Piezotron pressure sensing units each of which consists of a piezoelectric pressure transducer (Type 201B5) and a coupler (549B) connected with a 128M cable. The unit is then connected to an oscilloscope for the readout of voltage signals. Specifications of the Piezotron miniature pressure sensor or transducer, the Piezotron coupler, and the Textronix oscilloscope are presented in Appendix A.

The pressure of up to 100 psi was sensed by the mini-gage which gives a direct, high level, voltage signal with less than 100 ohms output impedance and high frequency response of 50

kHz and low frequency response of 0.005 Hz. The sensor then converts the pressure into electrical voltage with bias of up to 11 ± 2 volts. The power required by the transducer to operate is supplied by the coupler, and the signal from the transducer to the readout equipment is transmitted through the coupler over a single inexpensive cable. This eliminates all of the inherent piezoelectric high impedance problems of electrical leakage, cable noise, and signal attenuation and allows the transducers to be used in contaminated environments, with long and moving cables at low noise, without use of charge amplifiers.

The calibration of the transducers was performed at the factory, and the values of the calibration were noted to be, on the average for all probes, 50 mV per psi for the pressure measurement up to 100 psi. The calibration curve relating the voltage output and the pressure is noted to be quite lenient.

- **TEMPERATURE MEASUREMENT.** Due to the extremely transient nature of temperature variation in the recirculating flow as a result of the pulsed laser operation, a sensor of high frequency response in excess of 1 kHz is considered necessary for the temperature measurement. Search of an adequate sensor resulted in the selection of a hot wire sensor made of 0.00015 inch diameter tungsten wire coated with platinum powdery film. The hot wire sensor is connected to the Temperature and Switching Module (Thermo-Systems Model 1040) which, in turn, connected to the power supply (Model 1031-10A).

The module consists of a bridge circuit and amplifier in an open loop configuration so the hot wire sensor which is ordinarily used as an anemometer probe can be switched to function as a resistance thermometer. Since there is a linear proportionality between the voltage output and the temperature, the calibration can be simply performed by adjusting the zero and gain set potentiometers to a desired temperature range using the calibrate pots of two temperatures.

- **VELOCITY MEASUREMENT.** For the measurement of velocities, hot wire probes the same as those used for the temperature measurement is applied. The probe is connected to the constant temperature anemometer module (Model 1010A). The amplified output signal from the anemometer is sent to the Linearizer (Model 1005B) so that the voltage signal is processed in such a way that it became linearly related to velocity of the gas flow.

The use of these modules ensures the frequency response above 500 kHz with power output as high as 1.5 amps. The noise associated with the anemometer is noted to be less than 0.007 percent equivalent turbulent intensity. Frequency response to the Linearizer is found to be up to 400 kHz and the accuracy of linearization can reach ± 0.2 percent. With these special features of the instrument, it is able to measure both average velocity and turbulence in one-dimension.

Calibration of the probe is performed by using a Thermo-Systems Calibrator (Model 1125) in accordance with the furnished instructions. The readout system for both temperature and velocity is the Tektronix type oscilloscope (Type 564-3A74-3B3).

3. INTERFEROMETER SUBSYSTEM FOR OPTICAL MEASUREMENTS. The optical cavity is an area of primary concern in any laser system. In this section we propose to determine laser cavity characteristics under potential lasing conditions with optical diagnostics.

The laser cavity of the Closed Cycle Circulator is currently being considered as an amplifier, i.e., no mirrors will be used for outcoupling of power (Figure 4). The diagnostic test in this mode of operation is medium quality.

Medium quality measurement is the most important diagnostic to be measured optically. This test is broken down into two categories: a medium homogeneity category in which quantitative results will be obtained from steady state flow in the laser cavity; and a clearing time category, a qualitative visualization of shock structure created by E-Beam injection in the cavity with the impact of multiple geometry. The latter category will be measured as a function of time.

- Medium Homogeneity.

BASIC CONCEPTS. Interferometry is the basic investigative tool for medium homogeneity measurements. Its principle of operation is based upon detection of optical path differences (phase differences) along a line-of-sight [3]. Figure 5 shows a planer wavefront in the x, y plane incident from the left. The laser gas medium is shown flowing in the region from z_0 to z_1 . z being along the optical axis. The phase, ϕ , at any point in the x, y plane (assuming small deviations of the light rays along the z axis) is given by

$$\phi(x, y, z) = 2\pi/\lambda \int_0^{z_1} n(x, y, z) dz \quad (1)$$

where n is the local index of refraction of the media and λ , the wavelength of the illuminating beam. The index of refraction is related to the density, ρ , of the gas mixture by

$$n(x, y, z) = 1 - \beta \rho(x, y, z) \quad (2)$$

where β is the Gladstone-Dale constant of the gas mixture. The phase is then related to gas density by

$$\phi(x, y, z) = 2\pi/\lambda \int_0^{z_1} \{1 - \beta \rho(x, y, z)\} dz. \quad (3)$$

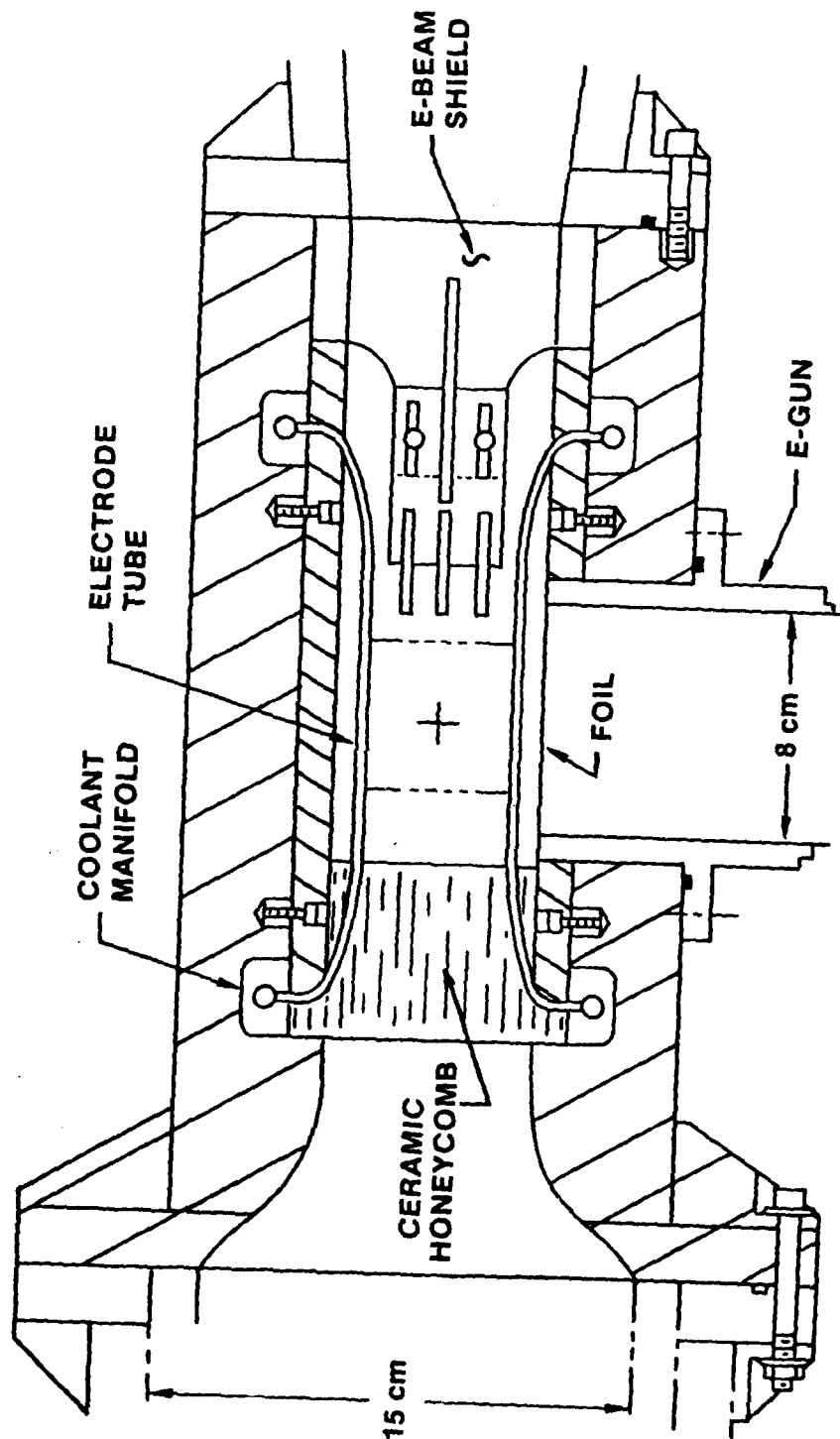


Figure 4. Closed cycle circulator cavity.

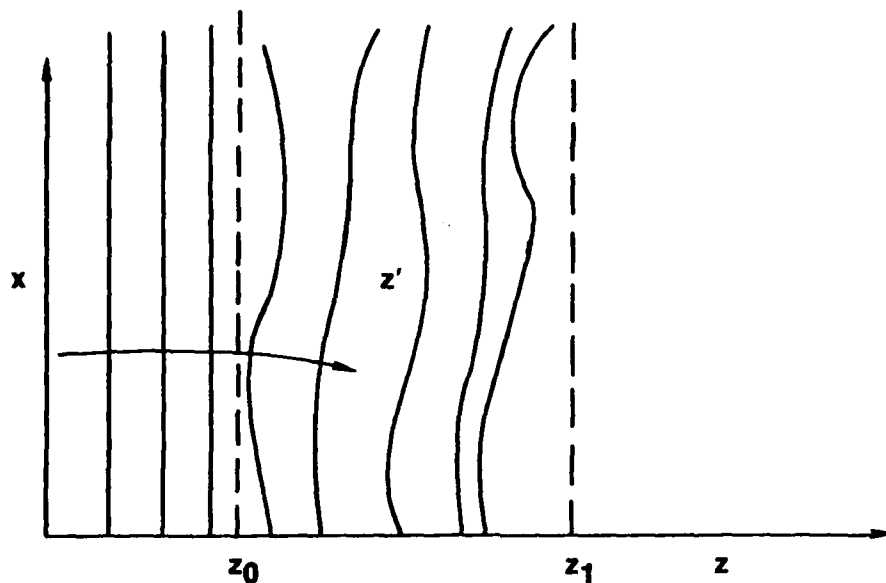


Figure 5. Transmission of light through an inhomogeneous media.

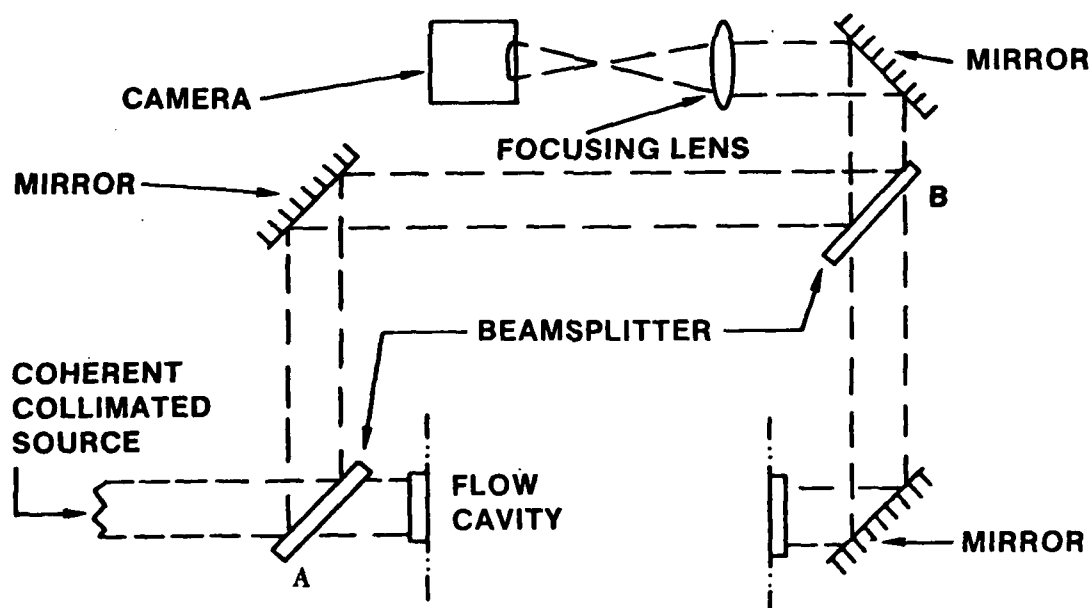


Figure 6. Mach-Zender interferometer.

However, only the phase distortions caused by the gas in the region from z_0 to z_1 are of interest. These would be given by

$$\Delta\phi(x, y) = \int_{z_0}^{z_1} \{1 + \beta\rho(x, y, z) - n_0\} dz. \quad (4)$$

The classical interferometers, e.g., Mach-Zender and Michelson interferometers, obtain $\Delta\phi$ by superimposing a planar wavefront reference beam with the perturbed test beam. The resulting interference pattern is recorded photographically. *Figure 6* shows the Mach-Zender configuration. Coherent light from a collimated source is shown incident upon the apparatus from the left. The coherence length of the source must be greater than the path length difference in reference and test beam. The light passes through beamsplitter A which divides the beam into a test beam and a reference beam. The reference beam passes to a folding mirror and onto beamsplitter B where it is recombined with the test beam to produce interference fringes. The test beam passes through the perturbing media in the laser reference in the laser cavity and is folded into the reference beam. The interference pattern is then focused into a camera for recording on photographic film. In this apparatus the test beam passes once through the cavity.

The Michelson interferometer is shown in *Figure 7*. In this case the reference beam is split at the beamsplitter and is returned upon itself by mirror A. The test beam is likewise returned upon itself by mirror B making a double pass through the laser cavity. The fringe pattern formed with the recombination of the beams is recorded in a similar manner to the Mach-Zender interferometer. The Michelson interferometer is more sensitive because of the double pass of the test beam through the laser cavity. However, for extremely strong flow disturbances, this apparatus can produce ambiguous results, the rays of the test beam not returning through the media along the same path.

-EXPERIMENTAL CONFIGURATION. The experimental setup (Michelson) for taking a single interferogram during steady state flow conditions is shown in *Figure 8*. A Q-switched pulsed ruby laser (20 μ sec pulse width) serves as a source. A coaxially aligned helium neon laser is used to align the entire optical train. A beam expander enlarges the laser beam into a large (8 inch) collimated beam incident on the interferometer. The interference fringes formed on the image of the flow cavity are focused on a camera.

The repetition rate of the pulsed ruby laser is limited to one pulse per 20 seconds. For real time interferometric analysis, the ruby laser will be replaced with a argo-ion laser of 4 w cw power. A Fastex motion picture camera having a frame rate of 10,000 frames per second would be used to record the interferograms.

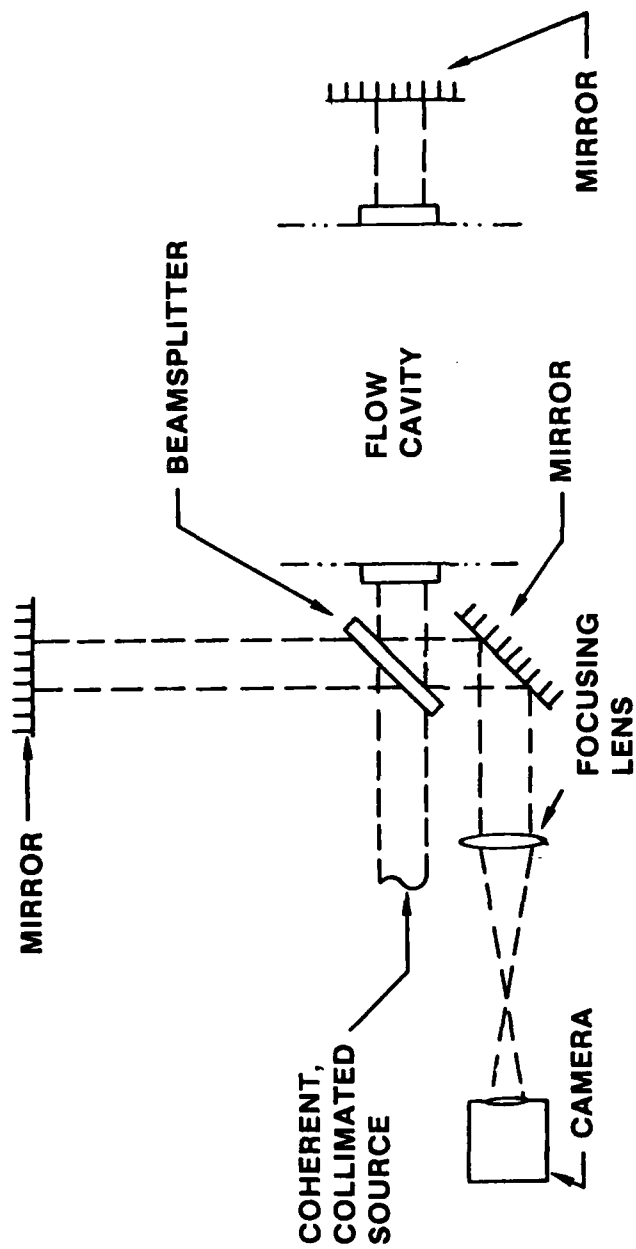


Figure 7. Michelson interferometer.

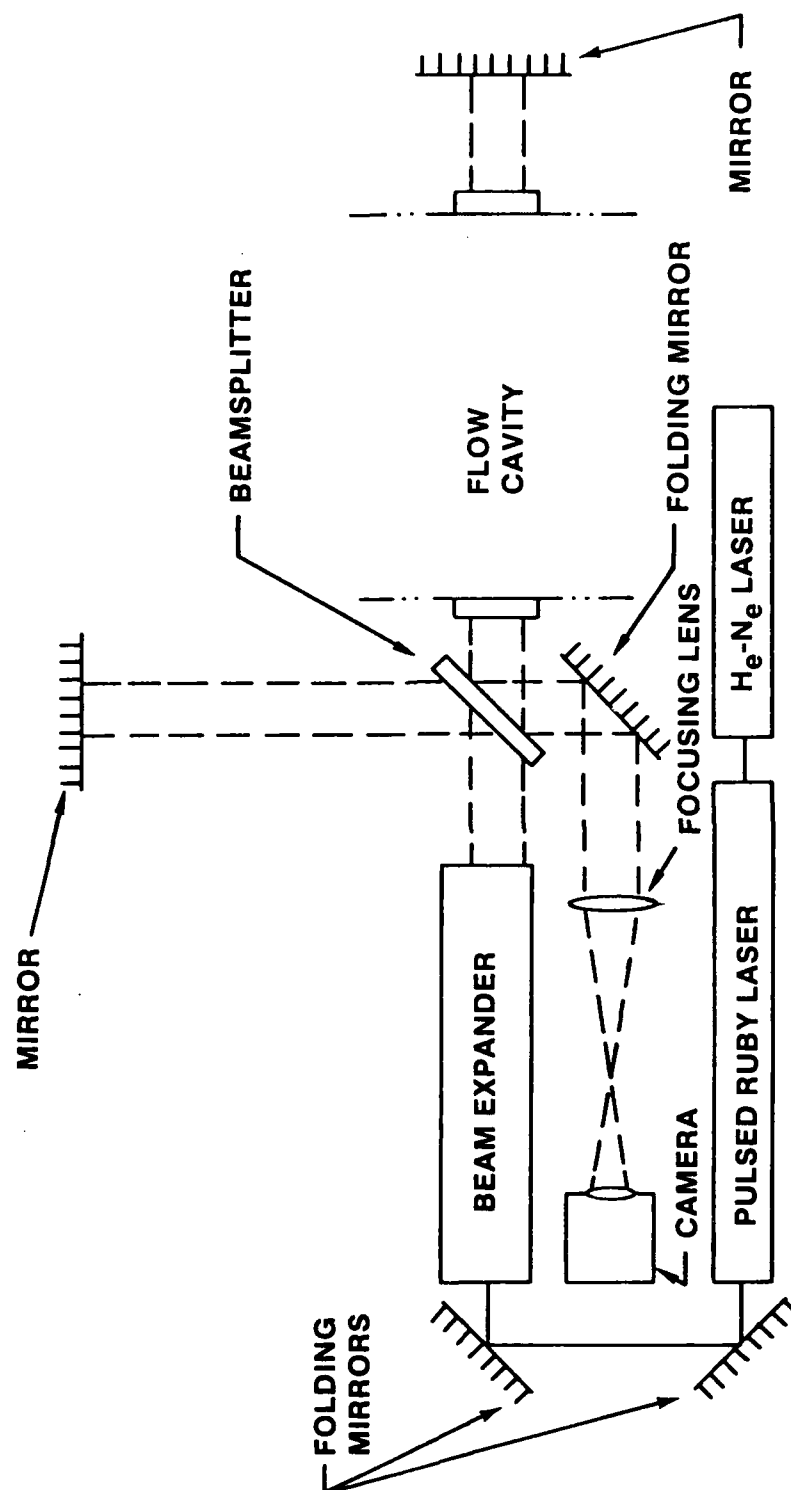


Figure 8. Typical experimental configuration.

-REDUCTION OF INTERFEROGRAMS. An interferogram taken by the Mach-Zender of Michelson interferometer is a contour plot of phase across the aperture of the laser cavity. The aberrations resulting from the passage of the planar wave test beam through the laser cavity derived from subtraction of a reference interferogram (taken prior to the test) from a test interferogram. We wish to determine the degradation such aberrations produce in the Fraunhofer pattern (far field pattern) of the laser cavity aperture. From the Huygens-Fresnel principle [4, 5] the amplitude of a wave near the focus of an optical system is given by

$$U(P) = -i/\lambda \frac{Ae^{-ikr}}{R} \iint_S \frac{e^{ik(\phi + s)}}{s} ds \quad (5)$$

where

R = radius of curvature of the reference wave (large).

k = propagation factor ($2\pi/\lambda$).

λ = wavelength at incident light.

A/R = amplitude of the wave in the exit pupil.

s = distance from a point on the reference wave to the observation point.

ϕ = aberration function.

S = exit pupil area.

If the point of observation P is at the focus of the reference wave, Equation (5) becomes

$$U(P) = -i/\lambda \frac{A}{R^2} \iint_S e^{ik\phi} ds. \quad (6)$$

The intensity at P is given by

$$I = I(P) = |U(P)|^2 = \frac{A^2}{\lambda^2 R^4} \left| \iint_S e^{ik\phi} ds \right|^2. \quad (7)$$

In the absence of aberrations, $\phi = 0$, and Equation (7) becomes

$$I_0 = \frac{A^2 S^2}{\lambda^2 R^4} \quad (8)$$

The normal intensity at the center of focal pattern (far field pattern)

$$I/I_0 = \frac{1}{S^2} \left| \iint_S e^{ik\phi} ds \right|^2 \quad (9)$$

Expanding $e^{ik\phi}$ and integrating termwise, the normalized intensity is

$$I/I_0 = \left| 1 + ik\bar{\phi} - \frac{k^2}{2}\bar{\phi}^2 - \frac{ik^3}{6}\bar{\phi}^3 + \dots \right|^2 \quad (10)$$

For small aberrations (small ϕ) we make the approximation

$$\begin{aligned} I/I_0 &\approx \left| 1 + ik\bar{\phi} \right|^2 = 1 - k^2(\bar{\phi}^2 - \bar{\phi}_0^2) \\ &= 1 - 4\pi^2/\lambda^2 (\bar{\phi}^2 - \bar{\phi}_0^2). \end{aligned} \quad (11)$$

Equation (11) is the standard root mean square (rms) wavefront deformation equation. A simpler, rough approach is to obtain a normalized density change, $\Delta\rho/\rho$, across the laser cavity aperture. From Equation (4)

$$\Delta\rho = \frac{\Delta S\lambda}{BL} \quad (12)$$

where

ΔS = maximum fringe shift across the cavity.

λ = wavelength of the probe laser.

β = Gladstone-Dale constant for the laser gas mixture at the laser wavelength.

L = length of traversed gas media.

Obtaining ρ , the average density of the media we have

$$\frac{\Delta\rho}{\rho} = \frac{\Delta S\lambda}{\beta L\rho} \quad (13)$$

The classical Mach-Zender and Michelson interferometers give interferograms which are phase contour plots. Interferograms obtained from a shearing interferometer require additional processing before phase information is derived.

Reduction of a shearing interferogram is shown by *Figure 8* [6]. First the fringes are arbitrarily numbered in consecutive order. Then reference points equal to the shear and parallel to the shear direction are placed on the test interferogram and on a reference interferogram. Interpolated fringe orders are obtained at each reference point on both interferograms. Proceeding from one edge of the interferograms to the other, the difference in orders at each point are taken and summed to those taken at previous points. This represents the phase at each reference point.

To obtain a complete phase contour map of the aperture, the reference point set may be arbitrarily translated. *Figure 8* represents shear in one direction (the y-direction). Complete phase information required shear in the orthogonal direction (in this case the x-direction).

After phase is calculated, data reduction follows the course described previously.

4. MASS SPECTROMETER SUBSYSTEM FOR TIME DEPENDENT MEASUREMENTS OF GAS COMPOSITION. The output of any laser instrument using chemical molecular species as the lasing medium, is dependent upon the population inversion of these species. The input electric discharge power can be reduced by small concentrations of species which attack free electrons. Thus, any change in the concentration of the lasing molecules or the formation of deactivating species will directly affect the total output power of the laser. This is true whether lasing is made to occur by a direct chemical reaction or by external stimulation such as an electrical discharge. Thus, the knowledge of the concentration of the lasing and certain other molecules is of great importance not only in the understanding of the chemical processes occurring in the laser, but can also serve as a monitor to correlate any changes in the laser output with changes in the gaseous concentrations.

Various analytical instruments are currently used as diagnostic tools in laser investigations. Each instrument is capable of yielding only a specific type of scientific information. Thus, a variety of instruments is needed to investigate the laser processed and the operation of any potential laser application.

The mass spectrometer is one of those essential analytical instruments which is used to analyze and monitor atomic and molecular concentrations of any species present in a gaseous environment.

Among the various commercially available types of mass spectrometer such as the quadrupole, magnetic, and time of flight, the latter has the broadest capabilities and maximum speed. It is also one of the least complex. It uses straight-line trajectory paths for all the ions formed in the source, employs a planar grid source, and collects all the ion masses on each cycle of the instrument with a magnetic multiplier ion detector. One may monitor every mass peak by an oscilloscope at intervals ranging from 1 to 50 μ sec depending upon the pulsing frequency of the particular instrument.

The mass spectrometer chosen to be used to detect and monitor various chemical species during operation of the small scale Closed Cycle Circulator is a Bendix Model MA-3A instrument. It has a spectral frequency of 30 kHz and a mass range of 0 to 500 atomic mass

units. It is capable of detecting and monitoring most gaseous molecules in the parts per million range.

A total of five different molecular species will be monitored by means of an analog scanner and a four-channel monitor which are accessories to the Bendix Mass Spectrometer. Both of these accessories are essential in order to use the instrument in a quantitative mode of operation. Both integrate the current output of each mass peak over a relatively large number of mass spectrum and present the integrated signal in an analog form for recording. The four-channel monitor operates in a multiplex mode, sampling each chosen mass for 128 cycles of the pulsing rate (3 to 5 milliseconds) and then shifting to the next mass peak. In this way, each of the four peaks is sampled every 15 to 20 milliseconds. Thus a considerable number of quantitative readings can be obtained during a 60 second run time specified in the Closed Cycle Circulator laser description. In this manner, it may then become possible to correlate certain events in the laser cavity with variations in the molecular concentration of specific species. The laser gas will be sampled at two locations as shown in *Figure 9*.

The gases in the laser cavity exhibit viscous flow whereas those in the mass spectrometer exhibit molecular flow. The change from the viscous to the molecular nature of flow may be accomplished in different ways. One technique is to probe with various leaks. Another method is the use of leak valves such as the Veeco PV-IQ valve. Such a valve is capable of going from fully closed to full open in 2 milliseconds. A preselected flow to the mass spectrometer will be achieved by a very fast precision leak valve.

Differential pumping is necessary to prevent an excessive amount of gases from entering the mass spectrometer and causing it to flood.

The mass spectrometer is an extremely sensitive instrument and is easily affected by external forces such as electric and magnetic fields (EMI). The presence of high electric fields, as may exist in the proposed Closed Cycle Circulator electric discharge laser, necessitated the location of the mass spectrometer to an area where such forces are minimized. Complete EMI shielding of the equipment is required to obtain accurate and reliable scientific information free from the EMI.

The planned recording and data acquisition of the data obtained from the mass spectrometer are shown in *Figure 10*.

The five monitored gases shown in *Figure 10* are H₂ (hydrogen), N₂ (nitrogen), CO₂ (carbon dioxide), O₂ (oxygen), and NO (nitric oxide). The time listing of any five desired gases

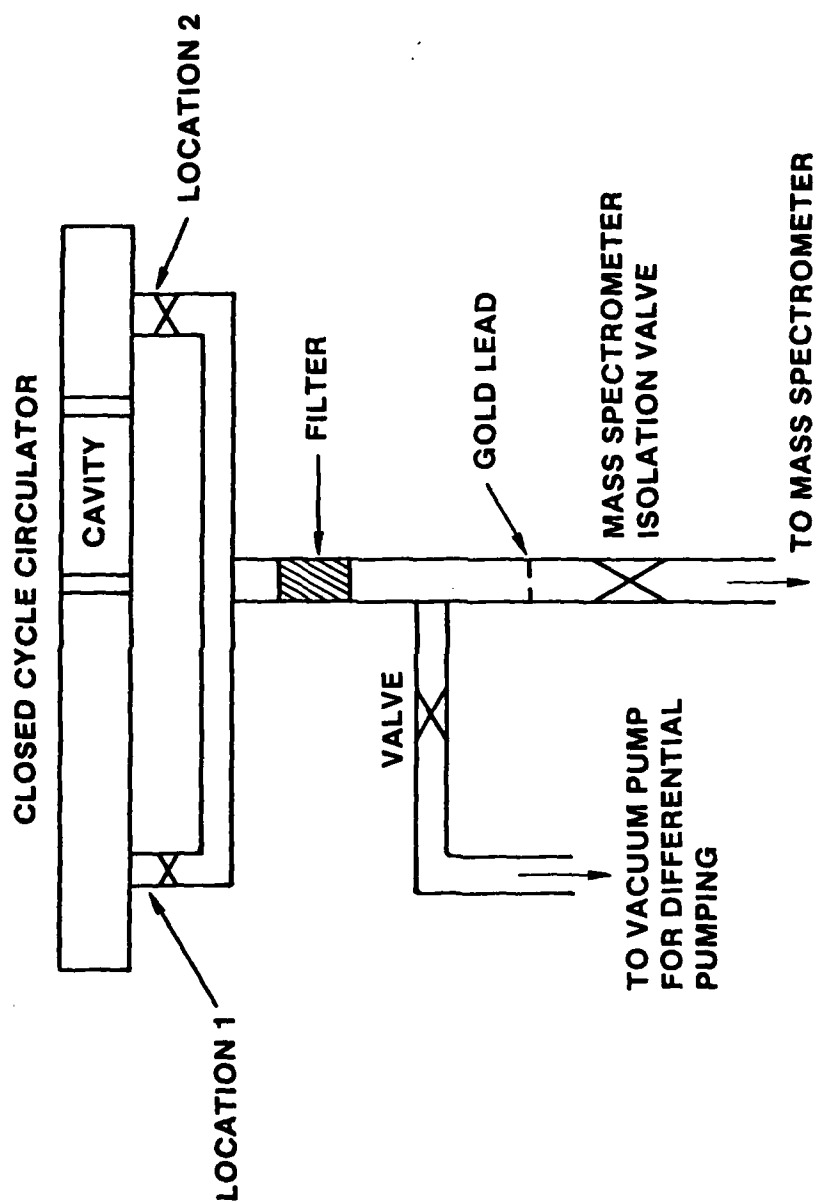


Figure 9. Sampling of laser gas at two locations.

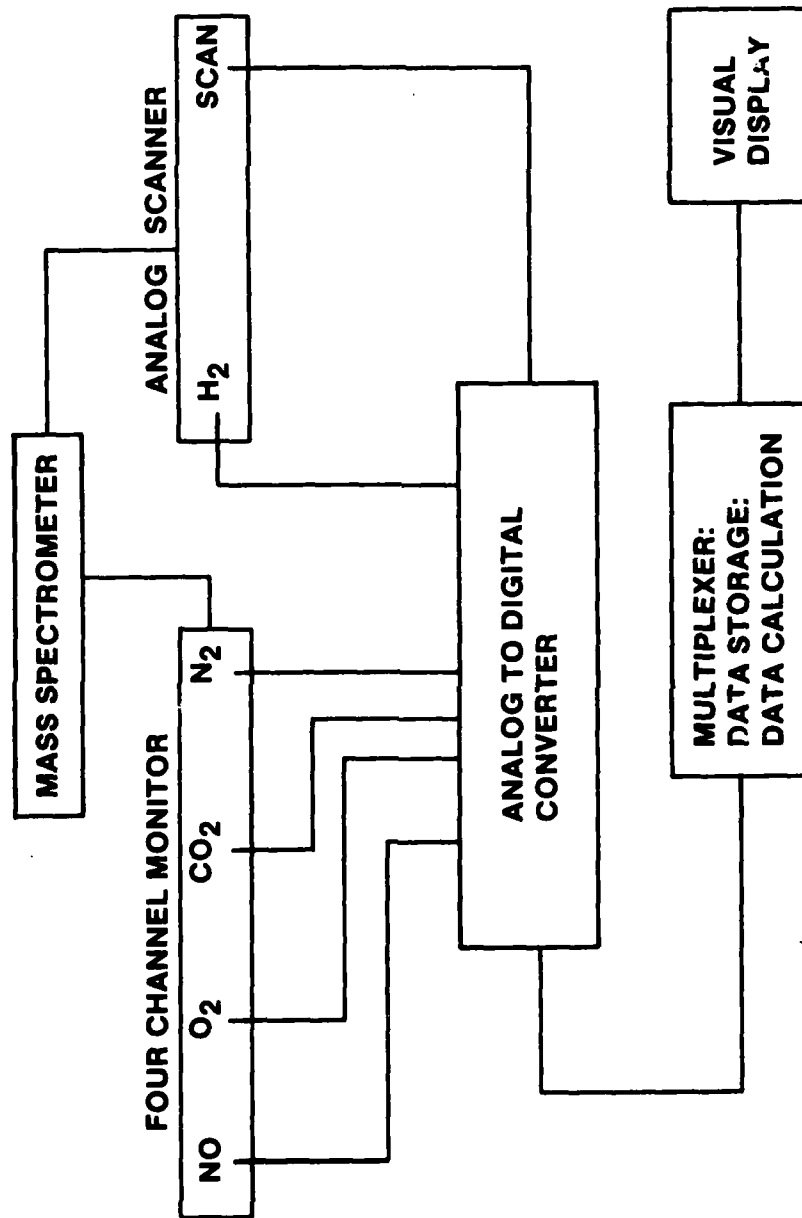


Figure 10. Block diagram of the data.

may be monitored by adjustment of the proper controls of the mass spectrometer. Hydrogen must be monitored with the analog scanner because of its relative mass spectrometer sensitivity. The analog scanner is considerably more sensitive than the four-channel monitor. N_2 and CO_2 will be detected as one peak by the MA-3 because they have the same mass, 28. However, techniques and computer programs are currently available that allow one to also determine the time history of CO_2 in the system. The scan control of the analog scanner allows one to qualitatively detect the presence of other gases which are not being monitored in any one experiment. The scanner may be triggered so that it will scan from mass 2 to mass 100 in less than one second.

In conclusion, the MA-3 time of flight mass spectrometer is an extremely valuable instrument, having many applications for chemical and electric discharge laser investigations. It allows one not only to monitor time changes in concentration of the prevalent gases but also to obtain a complete profile of other species. Its use in the Closed Cycle Circulator project will provide a data base for meaningful plasma-chemistry analysis and laser gas stability determination.

C. E-BEAM GUN AND POWER MODULATOR

The hot cathode E-beam triode gun with its driver and a vacuum subsystem, and a power modulator is used for applying energy inputs to the Circulator.

1. TECHNICAL SPECIFICATIONS.

- E-Beam Triode Gun

- Beam voltage - 125 to 200 kV.
- Foil area - 8 x 28cm.
- Discharge area - 5 x 25 cm.
- Post foil pulse current density for beam voltage of 200 kV - 1 to 100 mA/cm².
- Pulse width - 1.5 to 31 μ sec.
- Current rise time - 0.5 μ sec.
- Current fall time - 1.5 μ sec.

- Pulse repetition rate - 1 to 125 pps.

- Maximum on time per burst - 60 sec.

- Special feature - RF grid drive capable of 1 percent to 10 percent amplitude modulation of the gun current and frequency variable from 0.1 to 5 MHz.

- Controls - Separate controls are provided for repetition rate, pulse width and burst duration. Controls are available to operate with either single pulse or pulse burst mode. Following the last pulse of burst, the system will transmit an "off" signal to the power modulator and the circulator.

- **Power Modulator**

- Pulse voltage to load - 10 to 50 kV.

- Pulse length - 0.5 to 30 μ sec.

- Rise time - 0.5 μ sec.

- Fall time - 1.0 μ sec.

- Pulse repetition rate - 1 to 125 pps.

- Maximum energy per pulse - 650 joules.

- Maximum on time - 60 sec.

- Average output power capability - 100 kW.

- **Acceptance Test for Discharge Modulator**

- Modulator shall be operated into a 50 ohm resistive load with 1000 A load with 1000 A load current. The pulse width shall be 13 μ sec with 125 pulses per second. Operating time shall be 60 seconds.

- Ability to limit current and voltage to preset values shall be demonstrated.

- Acceptance Test for E-Beam Gun Assembly

- Post foil current density. Using a scanning collector having an aperture of 0.5×2 cm, a uniformity of ± 10 percent must be demonstrated over the 5×25 cm discharge foil area. Measurements will be made at 1 mA/cm^2 for $30 \mu\text{sec}$ pulses and 100 mA/cm^2 for $5 \mu\text{sec}$ pulses. The gun voltage will be 175 kV.

- Pulse width variability shall be demonstrated at 10 mA/cm^2 at 50, 100, and 125 pulses per second. The gun voltage shall be 200 kV.

- Pulse repetition shall be demonstrated at 10 mA/cm^2 , $10 \mu\text{sec}$ pulse width. The gun voltage shall be 200 kV.

- Sixty second burst operation shall be conducted at 10 mA/cm^2 , $10 \mu\text{sec}$, 125 pulses per second.

- RF modulation 0.1 to 5 MHz at 175 kV and 30 mA/cm^2 for $30 \mu\text{sec}$ pulses 10 percent modulation shall be demonstrated.

2. DISCUSSION OF CAPABILITY. *Figure 11* is a block diagram of the E-beam gun, power modulator, and the closed cycle gas circulator. The current in the E-beam gun is grid controlled and will be able to deliver 125 to 200 kV electrons to a foil window in the wall of the closed cycle gas circulator. The current density after passing through the foil can be varied from 1 to 100 mA/cm^2 . A special feature will be the ability to RF modulate the current in the frequency range of 0.1 to 5 MHz. The current modulation level can be varied from 1 to 10 percent. *Figure 12* shows the allowed and nonallowed operating margin. The E-beam gun power supply will be able to deliver up to 5 kW average power.

The master control will be used to actuate the pulse width, pulse repetition rate for burst mode or single pulse. It will also turn on the E-beam current $0.5 \mu\text{sec}$ before it turns on the power modulator and will turn it off $0.5 \mu\text{sec}$ after the power goes off.

The power modulator will be able to deliver pulse currents in the range of 100 to 1000 amps to the gas load. The gas load voltage can be varied from 10 to 50 kV. The modulator will have protective circuitry which will prevent damage to the modulator in the event of a load arc. In addition, the output pulse will be limited to a preset value in the event no load current develops or is less than the set value.

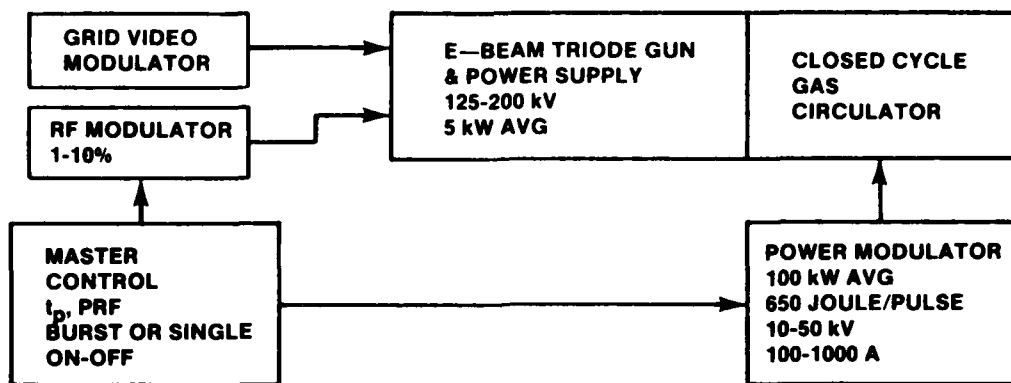


Figure 11. Block diagram of E-beam gun, power modulator, and closed cycle gas circulator.

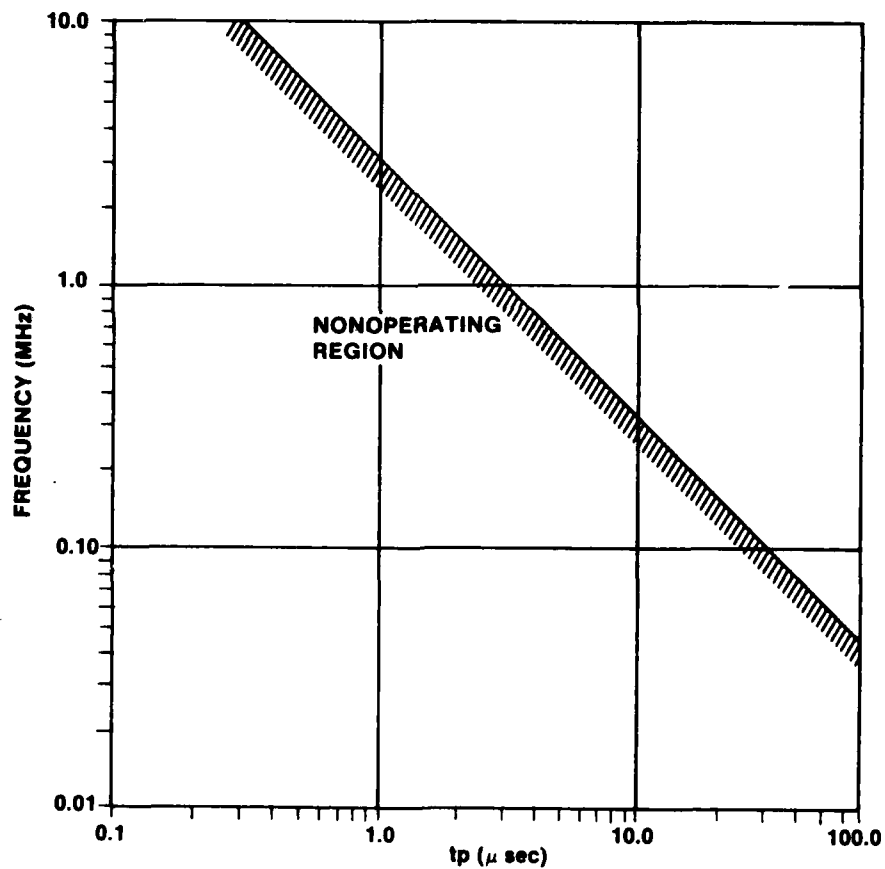


Figure 12. Modulating frequency versus pulse width showing the nonoperational space allowed.

D. DATA PROCESSING

1. DATA ACQUISITION AND RECORDING. The data acquisition and recording system includes a 64 channel (single-ended) analog-to-digital (ADC) for the interface to the test instrumentation. There is considerable flexibility available in the configuration of the ADC input voltage range (see the specifications below). The ADC includes a software programmable variable gain amplifier. Maximum specified data rate is 100,000 samples per second, but with the overhead burden of programs operating under the executive monitor, 10,000 to 20,000 samples per second may be a more reasonable figure. The ADC has interrupt capability so that much more efficient programming is possible given the availability of programmer manpower.

There presently is no clock in the system. Clock boards are available, however, and can be added at any time. The executive monitor will support both line and programmable clocks.

Depending on test requirements, data will be recorded on floppy disk or transmitted to a remote computer for recording on hard disk or magnetic tape, or both simultaneously. The diskette has limited space (256 Kbytes), while the communications line has limited bandwidth; therefore, an appropriate compromise will be necessary as to amount and frequency of data samples.

At the completion of any given test run, there will be several options available to experimenters for obtaining their data. Limited amounts of numerical data may be outputted on the 30 character-per-second console device. Copies of data may be obtained from the floppy diskette source. Data may be transmitted to a computer via modem and telephone. Because of the planned link to the graphics computer in Building 8972, hard copy plots from the CRT terminal, 7 track magnetic tapes, and 23KJ Disk-Pack capabilities will also be available. There is at present no line printer capability available. Hard copies of scaled, reduced numerical data would be available from the graphic terminal hard copy device.

Specifications of the system components are presented as follows:

- Processor/Controller
 - PDP-11/04 with M9301 bootstrap
 - 8K memory
 - Console keyboard with 30 characters per second, 132 column printer
 - Floppy disk system device:

Dual drives

10 Kbytes/sec maximum transfer rate

128 Kbytes of storage per diskette

- Four levels of hardware prioritized interrupt plus NPR
- I/O:
 - Console keyboard/printer
 - Floppy diskette
 - Analog-to-digital converter
 - Serial asynchronous interface, 75 to 9600 baud, full duplex

- Analog-to-Digital Converter

- ADAC Model 600-11
- 12 Bit digitizing
- Number of inputs (randomly selectable):
 - 64 single-ended, or (All inputs must be of
 - 32 true differential, or one type only)
 - 64 pseudo-differential
- Input voltage range:

Basic Range (Hardware) Selected)	Range Modification Using Programmable Gain Amplifier (Under Software Control)			
	(Volts)			
(Volts)	<u>x1</u>	<u>x2</u>	<u>x5</u>	<u>x10</u>
± 10	± 10	± 5	± 2	± 1
± 5	± 5	± 2.5	± 1	± 0.5
0-10	0-10	0-5	0-2	0-1
0-5	0-5	0-2	0-1	0-0.5

- Conversion time: Maximum of 100,000 samples per second
- Aperture time: 20 μ sec
- Interrupt capability for maximum response time

- Software

- RT-11 executive monitor system
- Assembler (Macro-11)

- Editor
- Linker, librarian, files handler, etc.

(Some of the capabilities of the software system and utilities will be restricted because of the small amount of memory.)

- Data I/O

Analog: - 64 channels of analog-to-digital converter input
 - No analog outputs (ADC has an unimplemented capability to provide two channels of analog output)

Digital: - No parallel digital inputs
 - No parallel digital outputs
 - One serial asynchronous I/O channel, full duplex, 75-9600 baud, full modem control, but no modem available

Test Data Results: - Console printer hard copy
 - Diskette (standard density, IBM soft-sectored)
 - Transmission via serial interface to IGDS in Building 8972.
 Data plots on graphic display terminal w/hardcopy
 Recording on 2315 disk cartridge
 Recording on 7 channel magnetic tape
 (nonstandard format)

The following *Figure 13* illustrates flow diagram of data acquisition and recording system:

2. SAFETY PROVISIONS. Since there are possibilities of oxygen deficiency in the room where the circulator is installed due to the discharge of liquid nitrogen from the cooling elbow into the room, an oxygen detector with hazard alarm set at 20 percent volume or less (Model ISA-30, Enmet Corp.) was installed on the room wall.

For safeguarding from possible pentane leaks from the heat exchanger loop, two pentane detectors with hazard alarm set at 10,000 PPM or more (Model ISA-3, Enmet Corp.) were installed: one at the pentane pump; and one on the room wall over the heat exchanger. The detection level may be lowered to 300 PPM with another detector for human health hazard in the near future according to the safety office requirements.

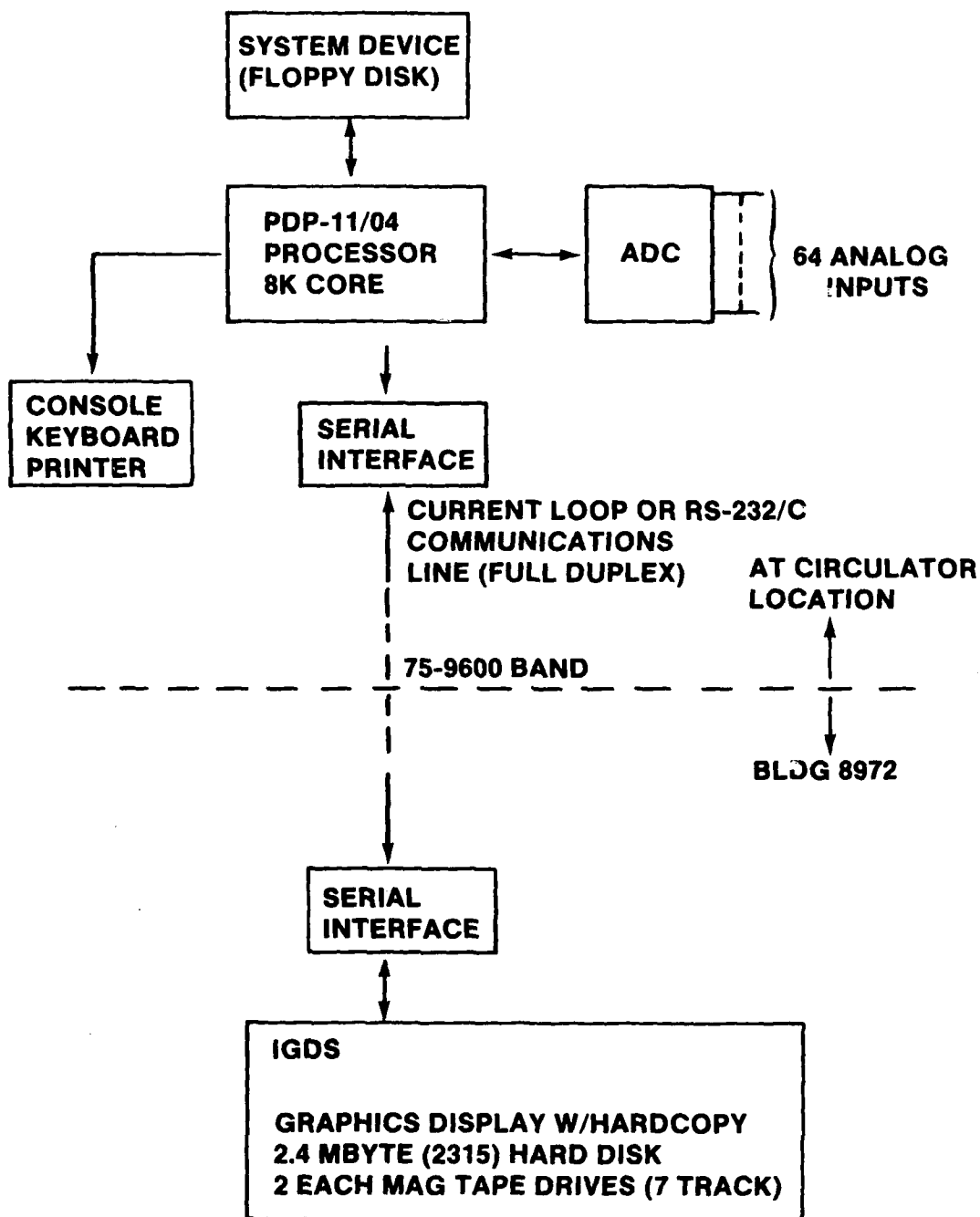


Figure 13. Flow diagram of data acquisition and recording system.

In addition, a double door is requested to be installed in the room for the purpose of venting the hazardous gases outside with a large fan. This task is assigned to the Post Facility Engineers.

3. ACOUSTIC ATTENUATORS. Two acoustic attenuators, one for upstream and one for downstream of the cavity, were designed and fabricated by Industrial Acoustics Company of New York under technical direction of Prof. Ingard of MIT. The details dimensions are shown in *Figures 14 and 15*.

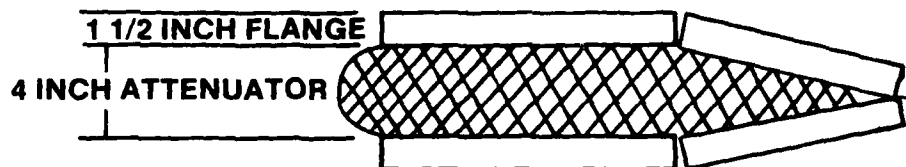
Technical basis of the attenuator design is explained in Dr. Ingard's report to the Army dated August 1978.

4. GAS REACTOR. In view of the possibility that laser gas may be contaminated or decomposed due to the pulsed energy input at the cavity which in turn causes material degassing or chemical reaction, the need for developing a catalytic converter capable of handling the laser gas at the specified temperature, pressure, and flow rates. Materials required to construct such a reactor have been acquired, but the necessary engineering design has not been completed due to the lack of pertinent data of the cavity flow.

3. SYSTEM OPERATIONS AND CONTROL

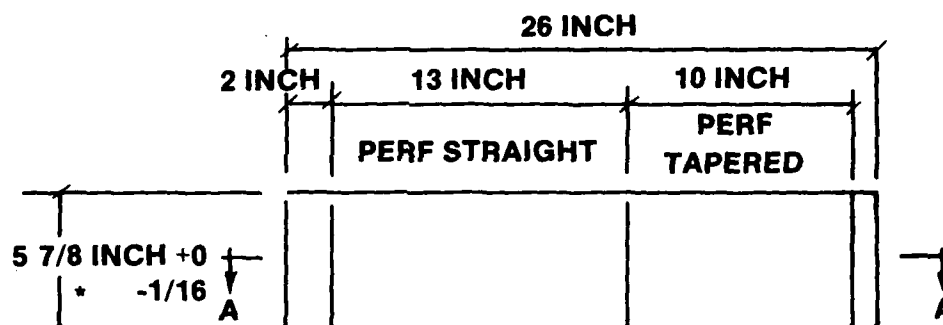
The control system may be categorized as follows: (1) gas circulator control elements, i.e., valve and sensors; (2) the electronic-control assembly; (3) the remote control operational panel. The gas circulator control elements are shown in *Figure 16*. They provide all the functions necessary for preparation and operation of the gas circulator.

The control valve signals are received by an electronic control assembly as shown in *Figure 17*. This assembly conditions all valve and sensor signals that interface with the gas circulator control elements; provides controller network and reference signals for the closed loop turbocompressor speed control; provides all sequential logic for system preparation and operation; and provides emergency control logic for safe shutdown and self-protection to the gas circulator. The electronic control assembly (located near the gas circulator) has two interface panels: the closed cycle gas circulator control harness and the remote control operational panel. The remote control operational panel is the control system link for the operator. It provides the operator with all information necessary for safe, efficient operation; displays critical system parameters; provides the switches and dials necessary for preparation and operational functions; warns the operator of out-of-spec parameters that may be an indication of an impending failure; informs the operator of the status of the system operation



FIBERGLAS ACOUSTICAL
FILL-OWENS-CORNING
TYPE 704 OR EQUIVALENT.

SECTION A-A



*TO BE INSTALLED
IN UPSTREAM DUCT
SECTION 5.906 INCH HIGH

UPSTREAM ATTENUATOR
(TWO REQUIRED)

Figure 14. Schematic of upstream acoustic attenuator.

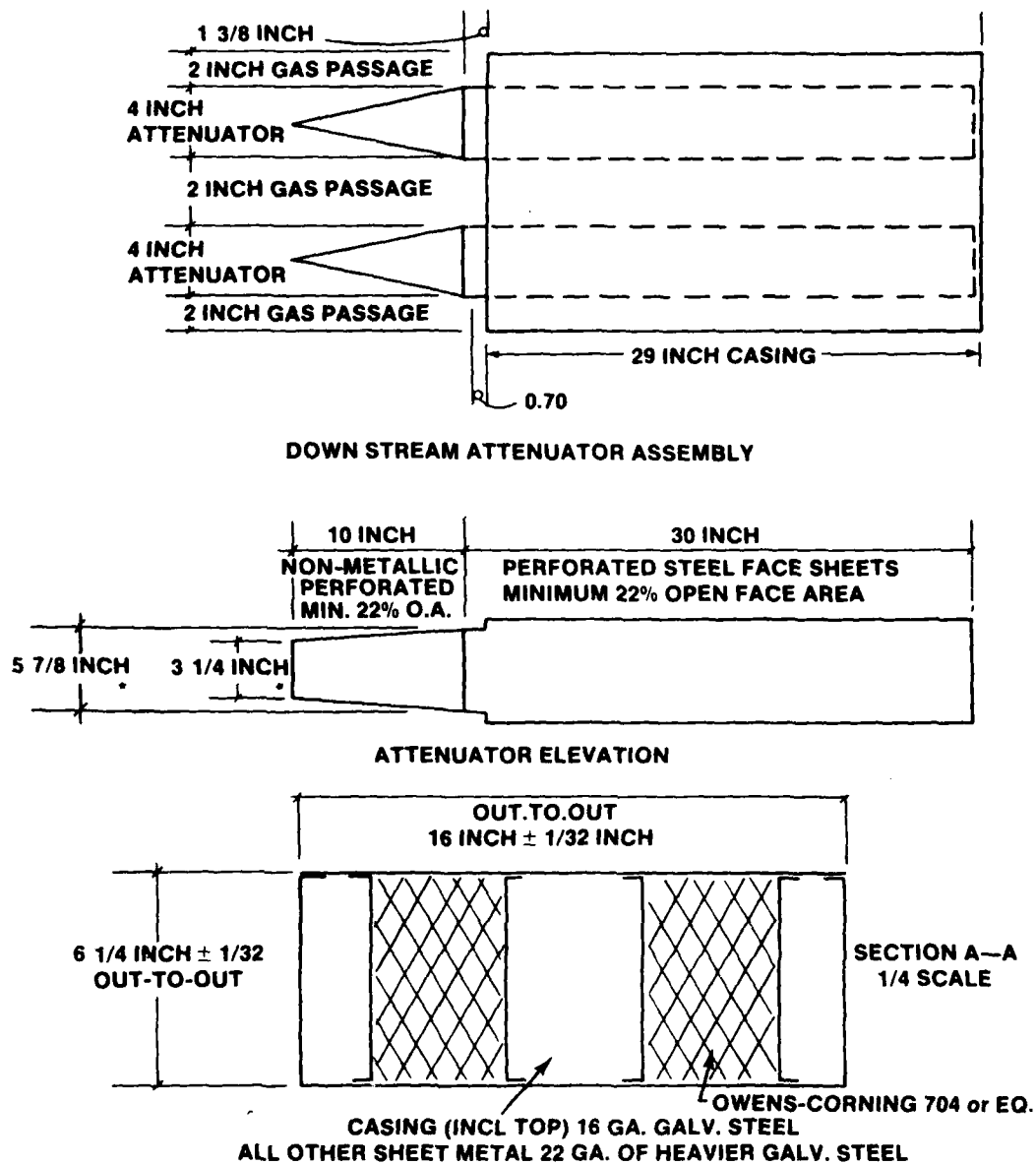


Figure 15. Schematic of downstream acoustic attenuator.

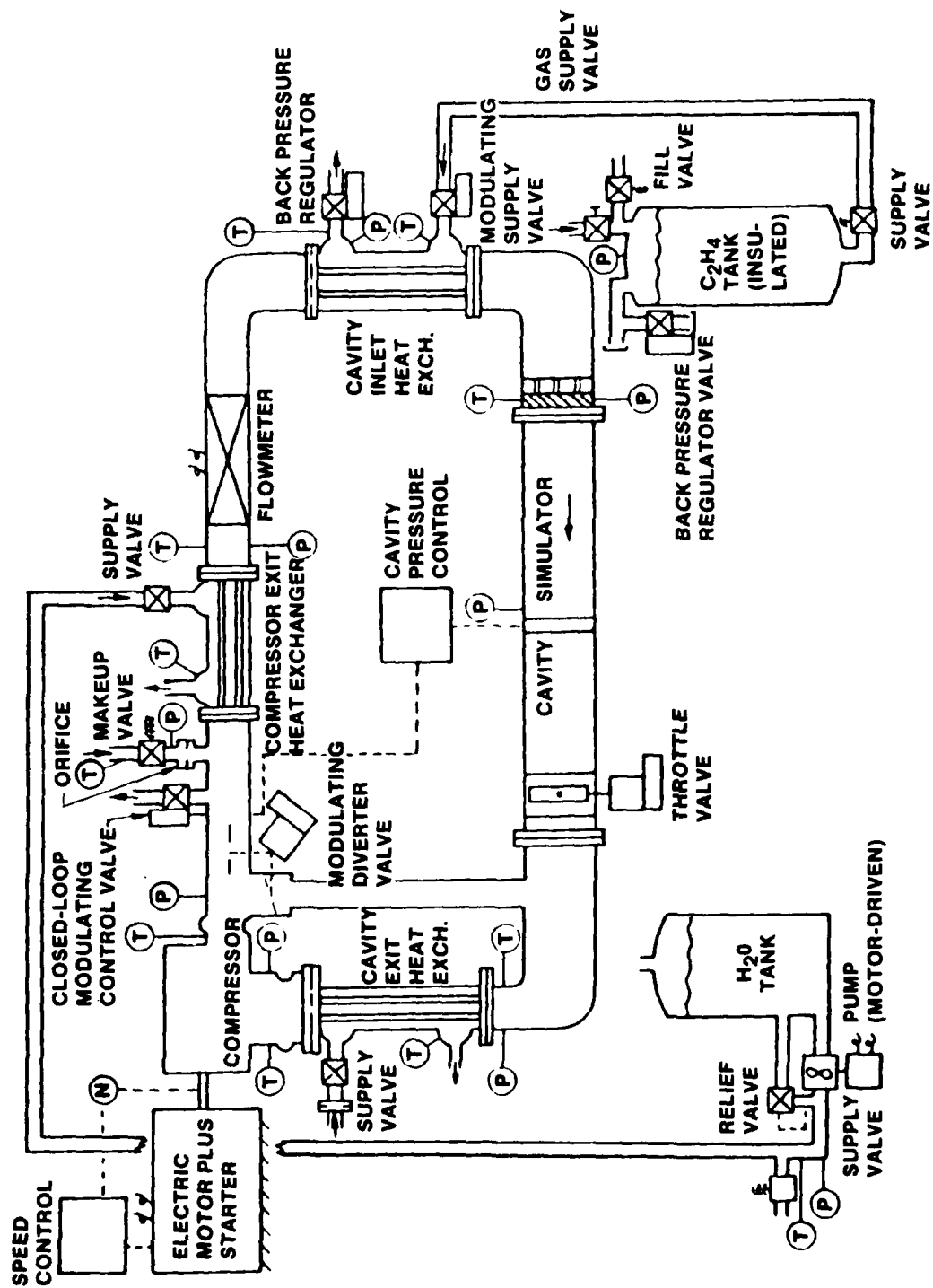
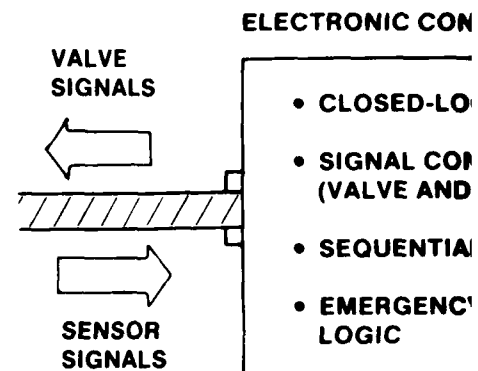
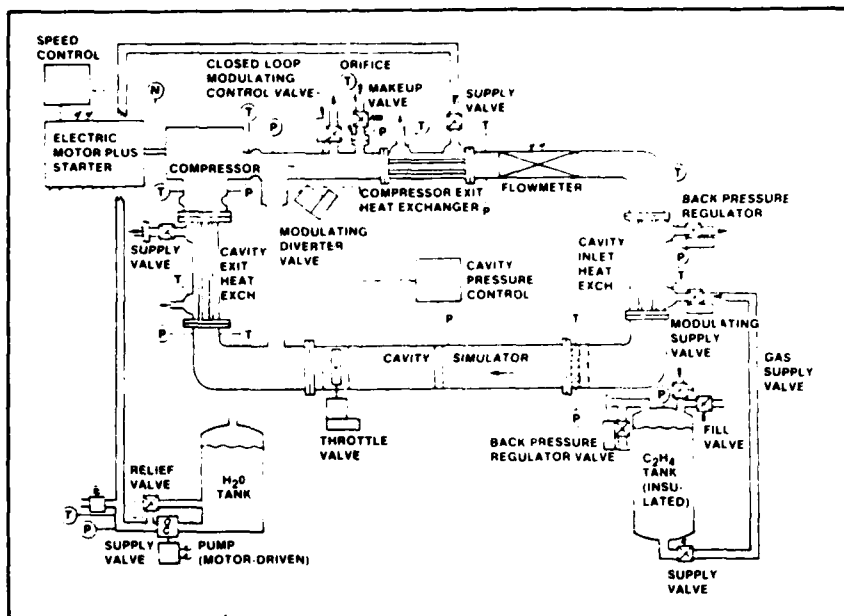


Figure 16. CCC control elements.

SUBSCALE GAS CIRCULATOR SYSTEM



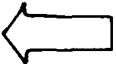
REMOTE CONTROL OPERATIONAL PANEL

- CRITICAL PARAMETERS DISPLAYED
- OPERATIONAL SWITCHES AND CONTROL SETTINGS
- EMERGENCY STOP
- OUT-OF-SPEC. WARNING SIGNALS
- SAFETY INTERLOCK
- OPERATIONAL STATUS LIGHTS
- FLARE IGNITER CONTROL
- PROPELLANT SUPPLY INFORMATION
- EXTERNAL DUCT HEATERS

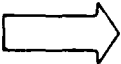
Figure 17. CCC control system.

ELECTRONIC CONTROL ASSEMBLY

**VALVE
SIGNALS**



**SENSOR
SIGNALS**



- **CLOSED-LOOP CONTROL**
- **SIGNAL CONDITIONING
(VALVE AND SENSOR)**
- **SEQUENTIAL LOGIC**
- **EMERGENCY CONTROL
LOGIC**

**DISPLAYED
STATUS AND CONTROL**

STATUS SIGNALS

STATUS LIGHTS

STATUS INFORMATION

STATUS

POWER SUPPLY

2

and status of propellant supply; provides an emergency of stop, safety interlocks, and control of ethylene flame igniter; and controls external duct heaters.

A. PREOPERATIVE CCC FUNCTIONS

The system is first evacuated by attaching a facility vacuum line to the gas vent valve (*Figure 16*). The turbocompressor oil system is decoupled to prevent oil leakage past the seals into the compressor. A hard vacuum is drawn (operational panel vacuum pressure indication), and external duct heaters are activated to vaporize any trapped moisture in the system.

A leakage test is then performed on the system. A clean gas mix is next introduced through the fill valve until the proper mass content is achieved. The mass of gas required to achieve a 15-psia cavity inlet pressure under lasing conditions is predetermined in the form of an average gas density throughout the loop. This is established by pressure and temperature transducers. Before coupling the turbocompressor oil system, compressor seal buffer gas is introduced by opening the solenoid valve. In many cases, the precharging of the system with mixed gas will result in subatmospheric pressure throughout the loop and, hence, compressor seal buffer gas is required to prevent oil or oil vapor from entering the system.

The premixed gas supply tank (GFE) is precharged with high-pressure gas. A pressure regulator at the discharge of this tank is set at approximately 100 psia. (The tank and regulator are not shown in *Figure 16*, and are not considered part of the deliverable closed cycle gas circulator system.) A fill valve orifice is selected to deliver from 0.5 to 5.0 percent of total system flowrate, depending on the rate of depoisoning desired during lasing operation.

The water and pentane coolant tanks are filled, with their isolation valves closed. The ethylene coolant tank is filled at ambient pressure (at a corresponding saturated liquid temperature of 170°K). The GN₂ supply valve is closed and the cap is removed from the tank vent valve. As heat from the environment enters the tank during a prestart waiting period, vapor pressure in the tank will rise to a maximum of 23 psia, at which point the tank vent valve opens holding that pressure and a corresponding saturated liquid temperature of 320°R.

B. CLOSED CYCLE GAS CIRCULATOR STARTUP

Preliminary to starting up of the compressor, the water tank pump is started up, and the pentane pump also started up. The gas diverted is set to a full bypass position. The gas throttle valve is set to a wide-open position. The compressor, oil pressure, and scavenge pumps are energized. A start signal by the operator at the control panel initiates acceleration of the

compressor. Due to the reduced impedance of the bypass line, the acceleration power requirements are minimized. The cavity exit heat exchanger wave flow valve will remain closed during the acceleration until such time as the gas temperature at the heat exchanger exit exceeds 315°K. At this point, a thermal switch will open the solenoid valve, allowing water to flow through the heat exchanger and thereby holding the exit gas temperature at the desired 320°K temperature. When the compressor reaches maximum speed, the motor frequency control will electrically modulate motor current, thereby holding the desired speed. If lasing is to be accomplished at a 200°K cavity inlet temperature, then the walls of the ethylene heat exchanger must be prechilled to approximately 320°K to permit nucleate boiling heat transfer on the coolant side of the heat exchanger. This prechilling operation is accomplished by opening the ethylene throttle valve wide open, which is remotely controlled from the operator's panel. The heat exchanger back-pressure regulator maintains 23 psia coolant vapor pressure. The gas diverter valve, controlled at the operator control panel, is set to a zero bypass condition, allowing full gas flow to the ethylene heat exchanger. When the gas exit temperature reaches 320°R, the prechilling operation is completed and the system is in readiness for lasing.

C. SYSTEM OPERATION

The gas diverter valve is modulated at the control panel until the desired cavity flowrate is indicated by the flowmeter. Cavity inlet pressure is noted, and the gas vent and/or fill valve is actuated as required to vary the system gas inventory. It is important to note, however, that the nonlasing cavity inlet pressure will in general be lower than the pressure under lasing conditions. To prevent a substantial pressure transient immediately following lasing, it is desirable to establish the proper gas weight in the system in the "ready" condition.

Cavity inlet temperature is noted. If lasing is to take place at 200°K the coolant throttle valve is opened wide and the adjustable back-pressure regulator is varied until desired exit gas temperature is achieved. The throttle valve is sized to provide a coolant flowrate such that approximately an 80 percent exit quality will exist at the coolant exit line under maximum power operation of the system. At reduced power operation (reduced gas flowrate), the use of ethylene coolant can be conserved by closing the coolant throttle valve and thereby reducing coolant flowrate. This valve should be adjusted closed until a rise in coolant exit temperature is noted indicating that some super heating is taking place in the exit line. An exit gas quality of less than 100 percent could then be re-established by a readjustment of the throttle valve to a more open position, until the exit gas temperature stabilizes.

If lasing operation is to take place at a cavity inlet temperature substantially higher than 200°K, then the ethylene heat exchanger operates in a superheating mode. The adjustable

back-pressure regulator is set for 23 psia. The coolant throttle valve is adjusted until the desired exit gas temperature is achieved.

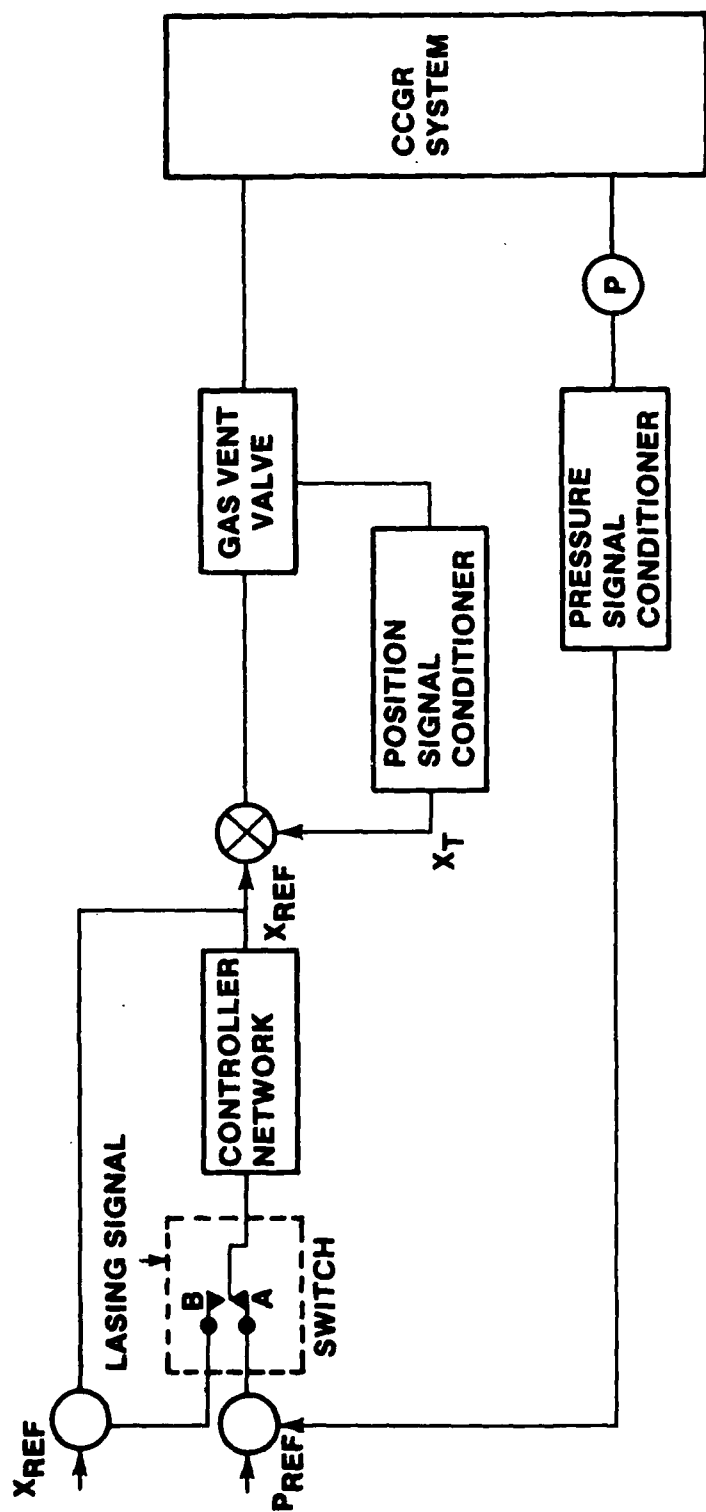
Upon activating the lasing switch on the operators panel, the solenoid fill valve is opened, introducing clean gas mix at a rate established by the orifice size. Lasing operating with 0.5 to 5 percent depoisoning is established by selection of the proper orifice. At the same time that lasing is initiated, the cavity pressure control is activated. This represents the only closed-loop control in the closed cycle gas circulator system aside from the frequency speed control of the compressor motor drive. The cavity pressure control is shown in *Figure 18*. A pressure signal at the cavity inlet is compared with a reference value of 15.0 psia. If an error exists between these two values, a proportional signal passes through a compensation network to establish a vent valve position reference which, in turn, is compared to a feedback position signal from the valve. A position error signal then actuates the valve servo to hold the desired position, and thereby maintain cavity inlet pressure at the selected value. Since the gas vent valve is sized to handle up to 5 percent of maximum gas circulator flow, there is no change necessary to the control should a different gas fill orifice be selected to change the depoison rate. During lasing operation, if it is desirable to vary cavity inlet pressure, this can be accomplished by simply selecting the new desired pressure reference at the control panel. The gas vent servovalve will automatically modulate to hold the selected cavity inlet pressure at the same depoison rate.

As shown on the control schematic of *Figure 18*, the system provides for either automatic or manual control of cavity inlet pressure depending on the switch setting. With contact B closed, the cavity inlet pressure is controlled manually by setting a gas vent valve position reference at the control panel. With contact A closed, a pressure reference is set up at the control panel. With contact A closed, a pressure reference is set up at the control panel and closed-loop control of cavity inlet pressure is established. The control system is so designed as to provide "bumpless transfer" between manual and closed-loop control. This means that a smooth transition will take place when switching between the two controls. Variations in cavity inlet temperature can be achieved by remote positioning of the coolant throttle valve at the control panel. This will vary the coolant flowrate and hence the superheat temperature at the coolant exit.

4. STANDARD OPERATING PROCEDURES

A. PURPOSE

This procedure is to establish safe operation standard for personnel and equipment in the operation of the Army Closed Cycle Circulator (CCC). The CCC is a device for loading energy



- (1) THE LASING SIGNAL ACTUATES SWITCH WHICH CLOSES CONTACT A, ACTIVATING CLOSED LOOP PRESSURE CONTROL
- (2) THE NON-LASING SETTING OF SWITCH (CONTACT B) PERMITS REMOTE MANUAL POSITIONING OF GAS VENT VALVE

Figure 18. Cavity pressure control schematic.

into laser gas and recirculating the gas to study the physics and engineering of closed cycle operations. No laser light is extracted from the device.

B. APPLICABILITY

This procedure is applicable to all operating personnel involved in all phases of operation of CCC in Room 13, Room 18 and south loading ramp, Building 8971. Visitors must comply to the same requirements of operators.

C. RESPONSIBILITIES

All operating personnel will be under the supervision of the Chief, Laser Science Directorate, High Energy Laser Laboratory or his designated representative. All operating personnel will be familiar with and observe these procedures. A copy of these procedures will be posted in the operating area. All non-operating personnel assigned to Building 8971 are responsible for reading, understanding this standard operating procedure, and cooperating with operating personnel to preclude personnel injury and/or equipment damage.

D. DESCRIPTION

The device is a closed gas circulator to provide a functional laboratory unit to evaluate the component interactions as they are affected by pulsed electric energy loaded in the laser gas. The system is made of the following components:

- Turbine compressor and 150 HP drive motor.
- Water cooling system (2 heat exchangers, water storage and supply)
- Pentane cooling system (heat exchanger, pentane storage tank, liquid nitrogen (LN₂) subsystem and supply equipment)
- Interconnecting ducts
- Control console
- Instrumentation

1. **LOCATION.** The CCC is located in Room 13, Building 8971. The control console is located in Room 18. The high voltage transformers and storage tank are located on the south

loading ramp adjacent to Room 13. Room 13 has pentane and oxygen level sensors and alarm systems. The loading platform has only a pentane sensor and alarm since it is not a confined area. The hazards involved for the CCC are:

- High voltage
- Displacement of oxygen by nitrogen
- X-ray
- Rotating machinery
- Noise
- Pentane (liquid hydrocarbon)
- Low temperature of LN₂ and pentane

2. **PREOPERATION.** The preoperational procedure calls for conditioning the system and checking all storage supply and vacuum systems. The turbine compressor-motor oil system heater must be energized to bring the oil up to operating temperature. The compressor seal gas system is activated and the system gas pressure controller is disconnected prior to evacuating the duct and backfilling with laser gas to one atmosphere. Close valves on instrument panel. Open valves to supply the turbine compressor motor oil cooler and the cooling water supply tank. Check the LN₂ and pentane supply system. Check all lines, hoses, and piping for signs of leaks. Verify the air pressure is up for operations of pneumatic control valves. Check power supplies for any signs of oil leaks and that all electrical connections are in place. Verify that all detector and alarm systems are on and operating. Check the E-beam vacuum for operating condition.

3. **OPERATION.** Reconnect the gas pressure controller. Verify water valves are open and water is flowing in system. Start flow of LN₂ to water supply tank. Open pentane valves and set pentane throttle valve to operating pressure. Start LN₂ flow to cool pentane system. Start pentane pump into cycle operation (approximately, one minute on - four minutes off). Open LN₂ valve to start flow to cool the duct. Start the compressor. Check to see that the gas flow in the duct is stable. Monitor temperature and pressure sensors for proper operating conditions. Remove grounds from E-beam and sustainer. Set control to load energy into the gas and record test data. (See Appendix A for detailed procedures.)

4. **SHUTDOWN.** Turn off the compressor at controller. Turn off recorders. Turn off operating controls and install all grounds to the E-beam and sustainer. Wait thirty minutes for the system to cool down then turn off all the switches. Turn off the LN_2 , pentane, and water valves. Shut down the instrumentation system.

5. **MAINTENANCE.** The routine maintenance is to check the oil level of the compressor, the oil damped pressure gauges and Daniel Flowmeter Turbine. Check the air compressor for water condensation and clean the water tank. Calibration of sensors and checking alarms shall be on a routine established by the manufacturer. Routinely inspect the piping to look for signs of leaks.

6. **PROTECTION.** Whenever the compressor is running, ear protectors are required in the circulator room. First aid procedures are included as Appendix B.

The above described procedures are submitted and pending approval by the Chief Safety Officer, MICOM.

5. CALIBRATIONS AND PREPARATION OF THE INSTRUMENTATION SYSTEM

A. HOT WIRE ANEMOMETER CALIBRATION FOR VELOCITY MEASUREMENT

1. **THEORY.** When the hot wire anemometer is calibrated for velocity measurement, the basic function of the anemometer is to keep the hot wire at a specific temperature (known as the operating temperature). As flow passes over the hot wire, the temperature of the wire drops. The anemometer must therefore step up the voltage across the hot wire to keep the wire at its operating temperature. Given several known velocities and their corresponding voltages, a plot of velocity versus voltage can be constructed. This will yield an approximately one quarter power curve. By applying curve fitting techniques, a relationship for velocity in terms of voltage can be derived. Henceforth, whenever the hot wire is exposed to a flow and a certain voltage is read, that voltage is merely read into the equation and the velocity of the flow can be found.

2. **PROCEDURE.** The hot wire (and probe support) is positioned in front of a hole in a pressure chamber. The flow of gas into this chamber is controlled through means of a pressure regulator, and the pressure inside the chamber is read from a manometer. A thermometer is also mounted in the chamber so that the fluid temperature in the chamber can be found. (See

Figure 19). Using this apparatus, the pressure and temperature of the gas inside the chamber (which is causing a specific flow across the hot wire outside the chamber) can be found. Then, using the relation:

$$V = \sqrt{\frac{2.0 \times CK \times R \times 32.2 \times (459.6 + \text{Temp}) \times \left[1 - \left[\frac{\text{Baro Press (14.7) / 760}}{\text{Press}} + \frac{+(\text{Baro Press} \times 14.7)}{760} \right]^{-(1.0 - 1.0/CK)} \right]}{1}}$$

Where: R denotes the gas constant

CK denotes the specific heat ratio,

the velocity of the flow across the probe can be found. By adjusting the regulator to several settings, the several known velocities needed for the calibration can be found.

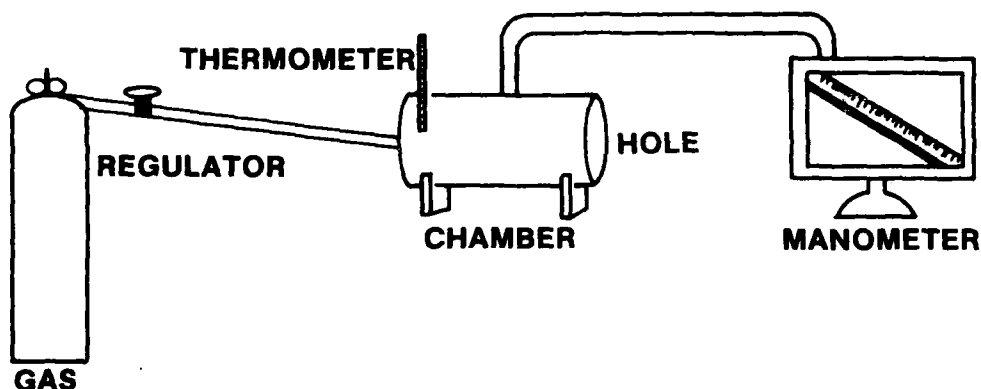


Figure 19. Calibrating apparatus.

The necessary voltages corresponding to these velocities are found at the same time as the velocities by simply reading a digital voltmeter which is hooked up to the anemometer. The only preparation that the anemometer requires is that the operating temperature be set. This is done as follows:

- Attach the hot wire and probe support to the PROBE jack on the anemometer with axial cable.
- Set the resistance dials to zero.

- Turn anemometer to STAND BY and switch power on.
- Using the 0-3 volt scale, adjust the REF SET knob so that the anemometer reads 2 volts.
- Depress the RES MEAS toggle and note anemometer voltage. If it decreases, the resistance setting on the resistance dial is too low. If it increases, the setting is too high. By interacting between adjusting the resistance setting and depressing the toggle, the cold resistance can be found (cold resistance will be at point where the voltage does not change when the toggle is depressed).
- The cold resistance is then multiplied by a given overheat ratio (a constant which depends on the type of fluid to which the wire is exposed) to get the operating resistance. This number is set into the resistance decks and specifies to the anemometer the operating temperature.

Once the operating temperature is set, the REF SET knob is adjusted so that the anemometer reads 15 volts. The anemometer is then switched to RUN, and the previously described procedure is used to calibrate the hot wire.

B. HOT WIRE ANEMOMETER CALIBRATION FOR TEMPERATURE MEASUREMENT WITH A HIGH DYNAMIC RESPONSE

1. **THEORY.** When using hot wires to measure temperature fluctuations, the anemometer serves to measure the change in voltage across the hot wire which is caused by a change in the wire's temperature. Since the resistance of, and therefore the voltage across, a conductor changes with temperature, we can derive an equation relating the change in voltage to the change in temperature:

$$\Delta V = K \Delta T \quad \text{where } K = \text{constant.}$$

If only one of the variables (preferably $T_{(nat)}$) is not known, we can solve the equation for this variable.

2. **PROCEDURE.** The equation used is as follows:

$$V - V_0 = R_0 J_0 OI(T - T_0).$$

where:

V_0 = initial voltage

V = final voltage

R_0 = cold resistance of wire at initial temperature

J_0 = temperature co-efficient of resistance for sensor being used

T = final temperature

T_0 = initial temperature

0 = amplifies gain (1000 standard)

I = current through sensor (1.5 mA standard)

Solving for T :

$$T = \frac{V - V_0}{R_0 J_0 G I} + T_0$$

T_0 can be measured at the experiments start, as can V_0 , R_0 , J_0 , G and I are known constants. V is measured with an oscilloscope.

3. Typical Data:

$$\Delta v = 2.7 \text{ divisions} \cdot 1.5 \text{ volts/div} = 1.05 \text{ volts}$$

$$T_0 = 38^\circ\text{C}$$

$$R_0 = 6.59\Omega$$

$$J_0 = 3.5 \times 10^{-6}$$

$$G = 1000$$

$$i = 1.5$$

$$T = \frac{1.05}{6.59(3.5 \times 10^{-2})(1000)(115)} + 39$$

$$T = 69.3^{\circ}\text{C}$$

Measured Temperature = 72°C

$$\% \text{ error: } \frac{169.3-721}{69.3} \times 100 = 3.9\%$$

The results are shown in *Figures 20 and 21*.

C. DETERMINATION OF HOT WIRE ANEMOMETER LINEARIZATION COEFFICIENTS.

When calibrating probes according to the method discussed, four separate pieces of data are collected and input to a computer. The four pieces of data follow:

- The barometric pressure
- The pressure read off the manometer
- The temperature in degrees of Fahrenheit
- The voltage across the probe, or the bridge voltage.

The output is the original voltage with a corresponding velocity. A function can then be found to relate the velocity in terms of voltage from a curve fit program. When the probe is in use then, the velocity of the flow across the probe can be determined by plugging that voltage into the function found from the curve fit program.

With the temperature, barometric pressure, and pressure from the manometer, a velocity is calculated which corresponds to a voltage but is not dependent on it. So, at another time, a different velocity may be calculated for the same manometer pressure due to changes in barometric pressure and temperature, but the voltage would change also because of the different velocity, shown on *Table 3*.

1. **LINEARIZER: SETUP AND PROCEDURE.** The 1052 Signal Linearizer is a device which uses four coefficients to straighten out a voltage-velocity graph. The calibration

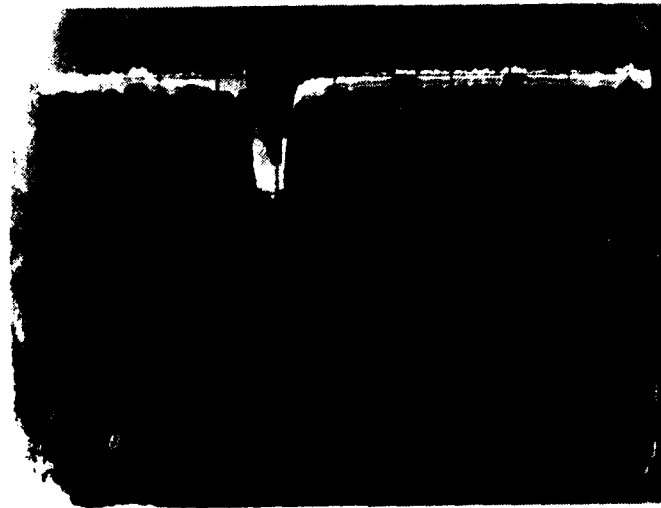


Figure 20. Oscilloscope photo of a typical temperature reading.

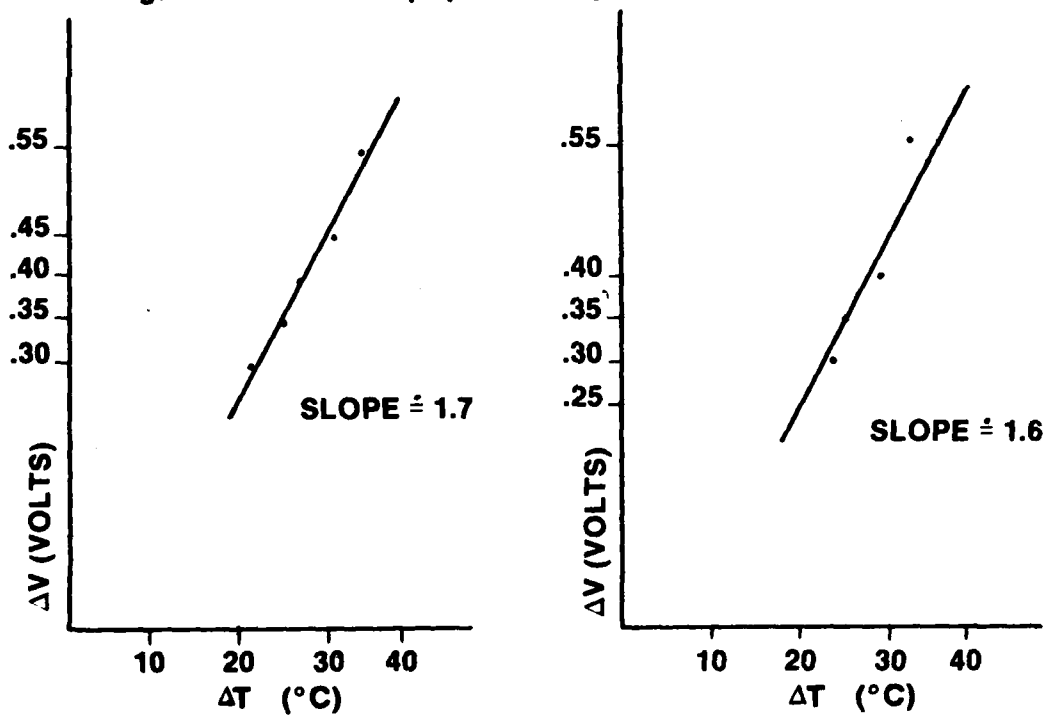


Figure 21. Plot of ΔV versus ΔT for same probe under two different initial conditions, showing repeatability.

TABLE 3. DATA FOR CALIBRATION OF PROBE 10**BAROMETRIC PRESSURE = 747.74**

PRESSURE	TEMPERATURE	VOLTS	VELOCITY
0	74.5	2.03	0
.02	74.5	2.59	11.923
.04	74.5	2.68	16.862
.06	74.5	2.75	20.652
.08	74.5	2.80	23.844
.10	74.5	2.83	26.659
.12	74.5	2.86	29.202
.14	74.5	2.89	31.542
.16	74.5	2.92	33.719
.18	74.5	2.94	35.763
.20	74.5	2.96	37.696
.30	74.5	3.05	46.166
.40	74.5	3.09	53.303
.50	74.5	3.14	59.589
.60	74.5	3.18	65.272
.70	74.5	3.21	70.495
.80	74.5	3.24	75.357
.90	74.5	3.27	79.922
1.00	74.5	3.30	84.237
1.30	74.5	3.36	96.022
1.60	74.5	3.41	106.500
1.90	74.5	3.45	116.027
2.20	74.5	3.49	124.821
2.50	74.5	3.51	133.027
2.70	74.5	3.54	138.222
3.00	74.5	3.56	145.663

procedure usually ends with the bridge voltage ranging from around 2 V for zero flow to about 3.5 V for 150 ft/sec velocity. Normally, this range results in a 4th power function relating the voltage and velocity. The linearizer takes the inputted voltage, (in our case anywhere from 2 V to about 3.5 V) and stretches it out over a range of 0 to 10 V.

The main purpose of the linearizer is to give a graph which is easier to read off velocities corresponding to voltages and to make it easier to read electronic devices which would be monitoring the output signal, whether linearized or not. (See *Figure 22*.)

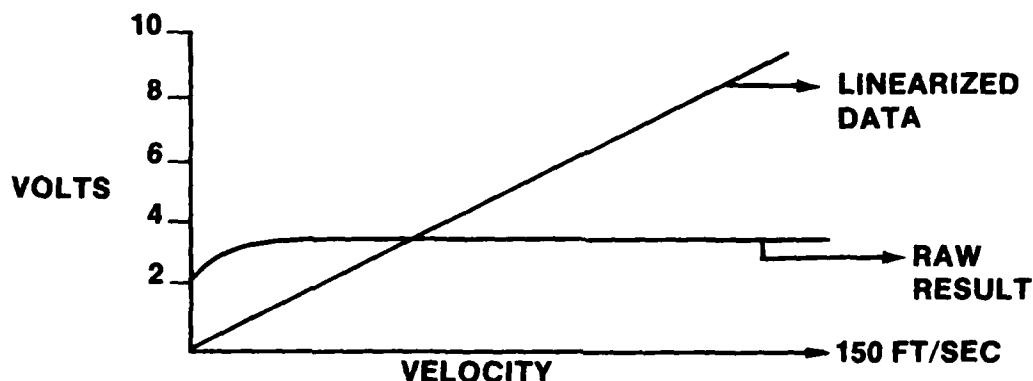


Figure 22. Linearizer setup and procedure.

2. PROCEDURE FOR SETTING UP THE LINEARIZER. The coefficients that are used depend on the characteristics of each probe and therefore are calculated from a probe's voltage-velocity relationship. The coefficients used here were calculated on a computer at the lab, utilizing aspects of the Thermal Systems, Incorporated (TSI) program given in the handbook on the 1052 Linearizer.

To begin, attach a digital voltmeter to the output jack on the linearizer. Turn the knob to OUTPUT. Under INPUT, turn the knob to COEF. SET and then place all the toggles under POLYNOMIAL COEFFICIENTS in the neutral position. Of the four coefficients calculated, check to see if all the coefficients are less than 10. If they are less than 10, then put the toggle under OUTPUT in the X1 position. If a coefficient is greater than 10 but less than or equal to 20 put that toggle in X.1 position. Take the first coefficient, A, and place the A toggle in either the positive or negative position determined by the polarity of A. Then adjust the potentiometer corresponding to A until the number displayed on the digital voltmeter is the same as the coefficient. When this is completed, return the toggle to the neutral position and go to the next coefficient. Repeat all steps until all coefficients are set. Then place all toggles into

the correct position whether positive or negative. A check at this point is to see if the voltmeter is reading 10 V. (Note: if toggle is in X.1 position, then the voltmeter would read 1 V.) The coefficients are now set. To set the span, turn the knob under INPUT to either REAR or EXTERNAL. REAR is used if taking voltages directly from a probe while EXTERNAL is used when supplying a voltage through a source. To check to see if the linearizer coefficients are correct, supplying a voltage is the most efficient course. Put in the base voltage of the probe. This value should correspond to zero after linearization. Adjust the output at the digital voltmeter until it reads zero by adjusting the ZERO SUPPRESS. When zero is reached, then input full scale voltage. A linearized signal of 10 V should result. Adjust the SPAN (FINE) until 10 V is reached. For these purposes, SPAN (COURSE) is set at 3. Return to base voltage to see if the linearizer is still producing 0 V. If not, once again adjust ZERO SUPPRESS. Return to full scale voltage to see if the linearizer is still producing 10 V. If not, adjust SPAN (FINE). The linearizer is now ready for different input voltages. A graph of the linearized output of a probe's voltage follows as compared to the raw input data (*Figure 23*). The calculated coefficients are also shown. This graph and the calculations are for Probe 10. The program used to calibrate first the velocity and finally the linearizer coefficients is also shown.

D. TRANSDUCER CALIBRATION

Transducers are small sensing elements that detect pressure differentiation. The end of a transducer contains a small crystal, electrically connected, in contact with a metal diaphragm. With a change in pressure, the diaphragm is pushed in which applies stress to the crystal. The crystal deforms because of the stress and this deformation causes a voltage to occur across the electrical connection. From the manufacturer it is known for each transducer what the relationship of millivolts per psia is, so the value of psia can be determined when the voltage is recorded.

The transducers for this project were calibrated in the following way: A cylinder with openings at either end and a port in the middle was used as the pressure chamber. The port was closed. At one end, gas was pumped in until a certain pressure was reached. At the other end, the opening was opened which allowed it to go to atmospheric pressure. A transducer, connected to an oscilloscope, was placed at the end which was at atmospheric pressure. Then, with the transducer end at atmospheric and the other end at a certain pressure, the port in the middle was opened. The change in pressure indicated by the transducer was recorded on the oscilloscope screen. At .02 V per division, the voltage produced by the transducer is found and, from there, the differential pressure is found. Ideally, the pressure calculated from the

THURSDAY 23 AUGUST 1979 10:11
 PROBE 10, NEWEST CALIBRATIONS IN LASER GAS DONE WITH TLC

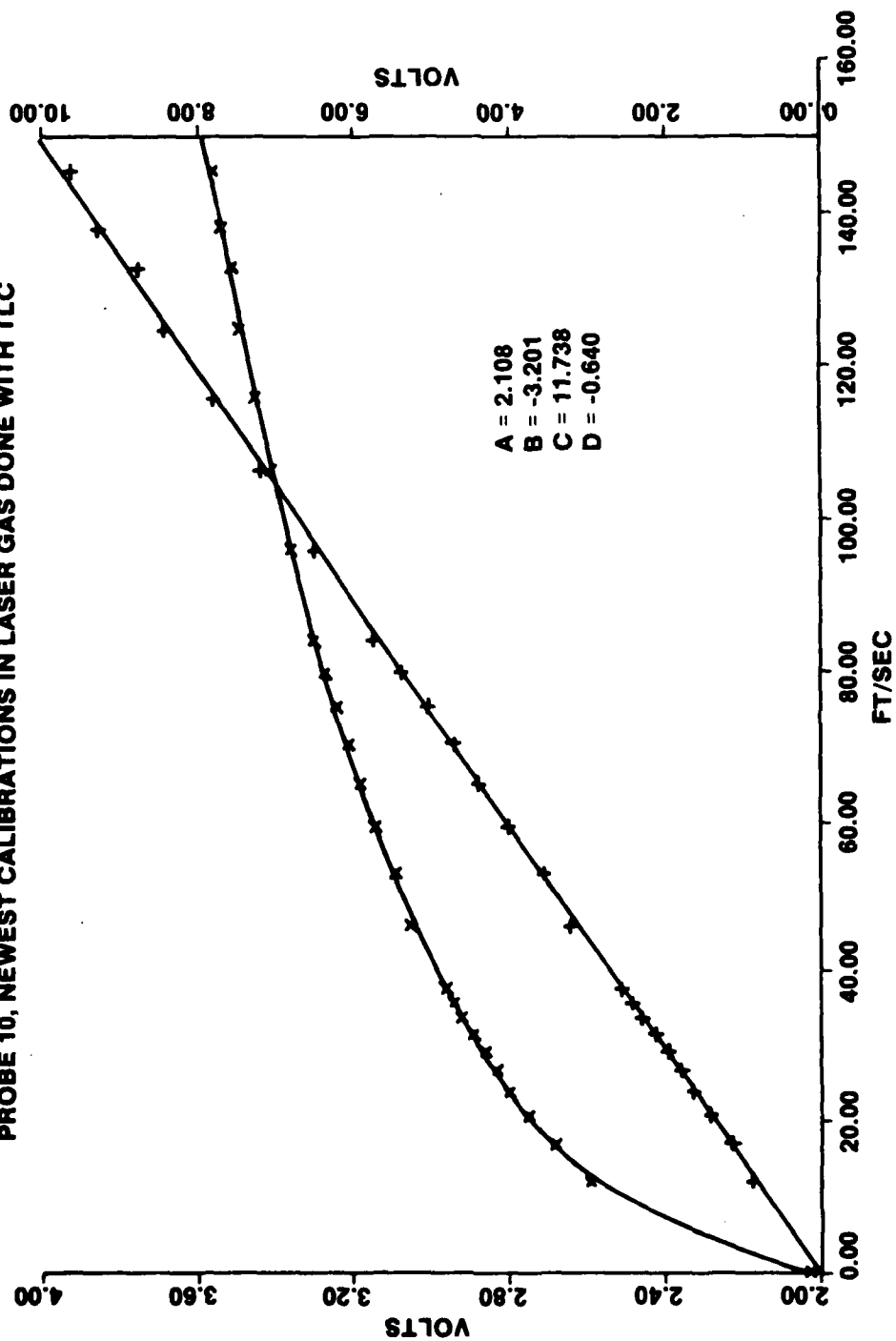


Figure 23. Typical calibration and linearization curves for the hot-wire anemometer.

transducer should equal the pressure of the end pumped up with gas. Realistically there are differences.

E. FLOW METER CALIBRATION AND CHECKOUT

For measuring mass flow rate of the recirculating laser gas, a Daniel electromagnetic gas turbine meter (8 inch size Model No. 2000-0) was mounted in the circulator. In order to ensure the accuracy of the meter, a test series was devoted to perform a calibration process. In the series, the data collected from the Daniel meter in terms of pulses per second (Hz) were converted into mass rates of flow based on the conversion factor furnished by Flow Calibration Facility of Daniel Industries, Inc.

The data from the meter were compared to the data obtained from the Pitot-static tube inserted at the cavity section with reasonable accuracy. The mass flow rate measured with the Pitot-static tube at the cavity section was obtained through use of integral method for the velocity distribution curve across the cavity section.

Figures 24, 25, and 26 show the relationships of pulse versus diverter valve opening, and Pitot-static pressure versus pulse obtained experimentally from the calibration process. Three test series 13, 14 and 15 shown in the figures demonstrate the repeatability of the flow meter. Figure 27 presents the velocity profile measured across the cavity center plane section by the use of the Pitot-static tube. It shows some slight variation in velocity across the section; however, the average velocity obtained from the profile through the integral method made the comparison with the flow meter data possible and verified the flow meter reliability and accuracy.

F. INTERFEROGRAM ANALYSIS

Laser cavities often use flowing gas systems. It is therefore important that the gas density be uniform if the laser light output is to be uniform. Systems using large electric fields must have density uniformity or possible arching due to sparks could result.

To experimentally determine the laser gas density, and the uniformity in any time frame of a laser pulse, interferometry techniques are used.

In the Closed Cycle Circulator System, light from ruby laser is used to analyze the gas density. The end result is a photograph of the light that passes through the laser cavity superimposed on light which bypassed the cavity.

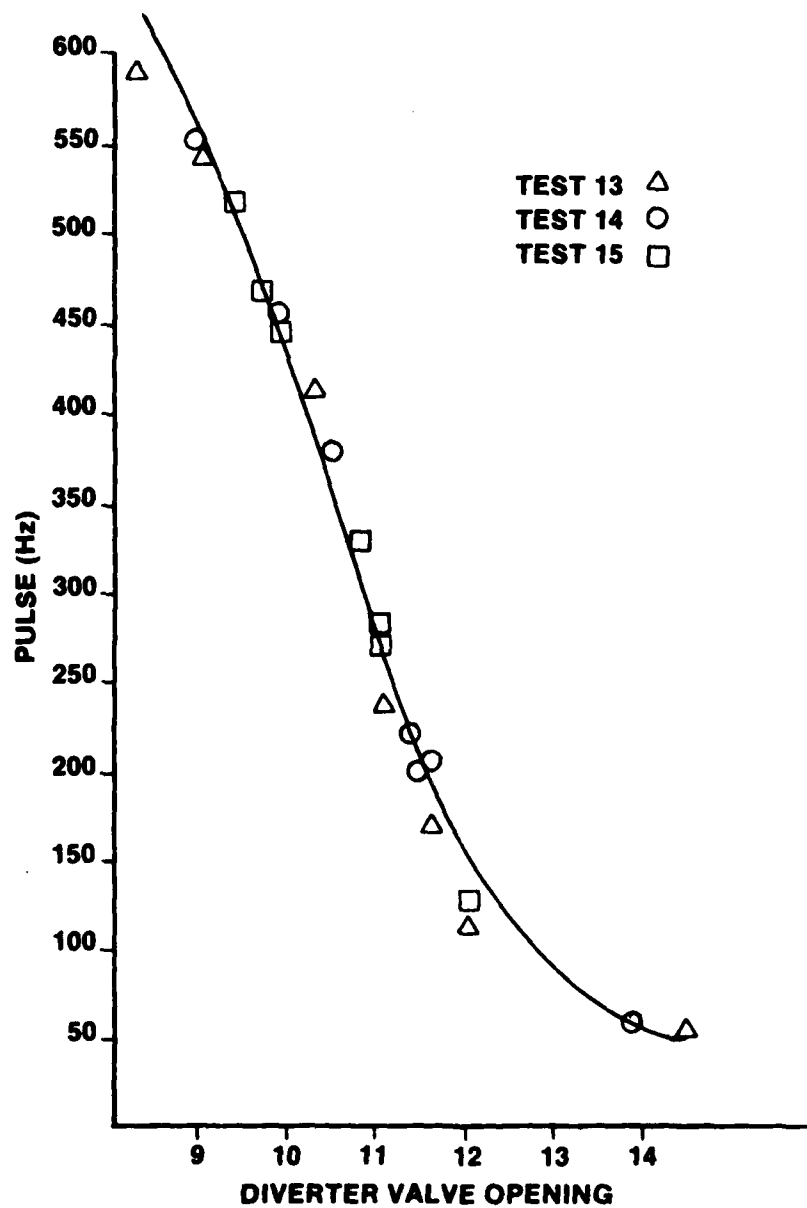


Figure 24. Pulse versus diverter valve for test series 13, 14, 15.

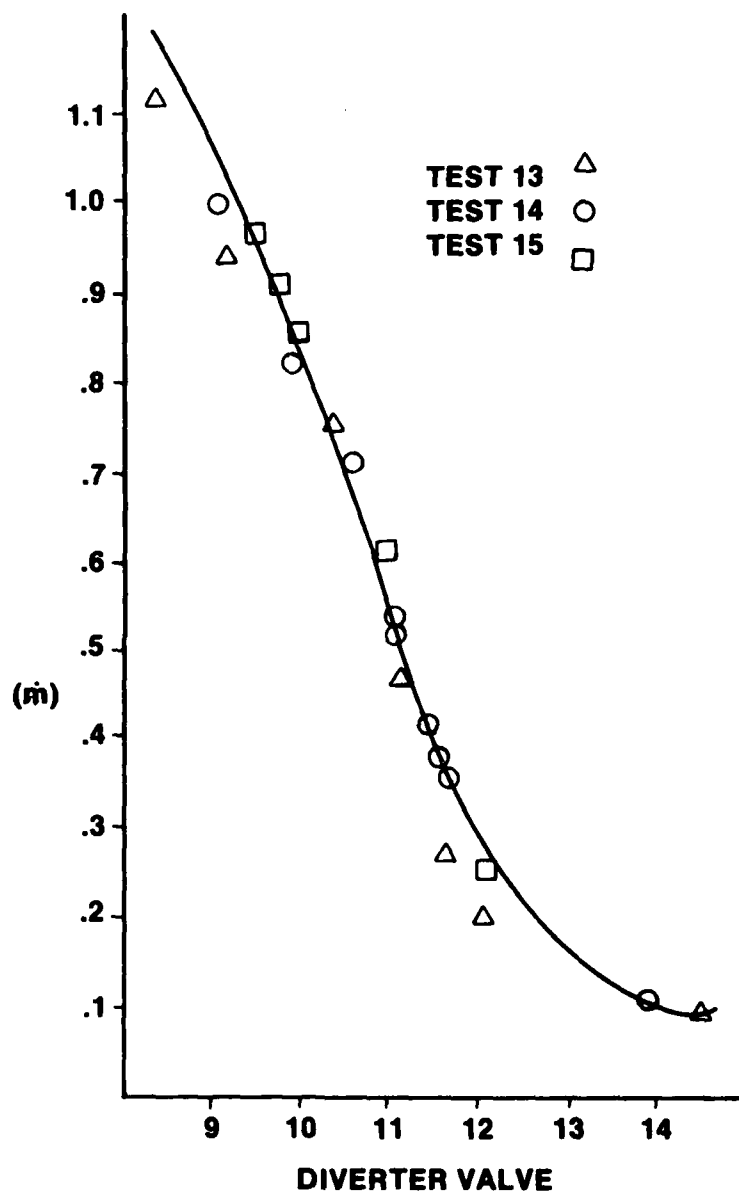


Figure 25. Mass flow rate versus diverter valve for test series 13, 14, 15.

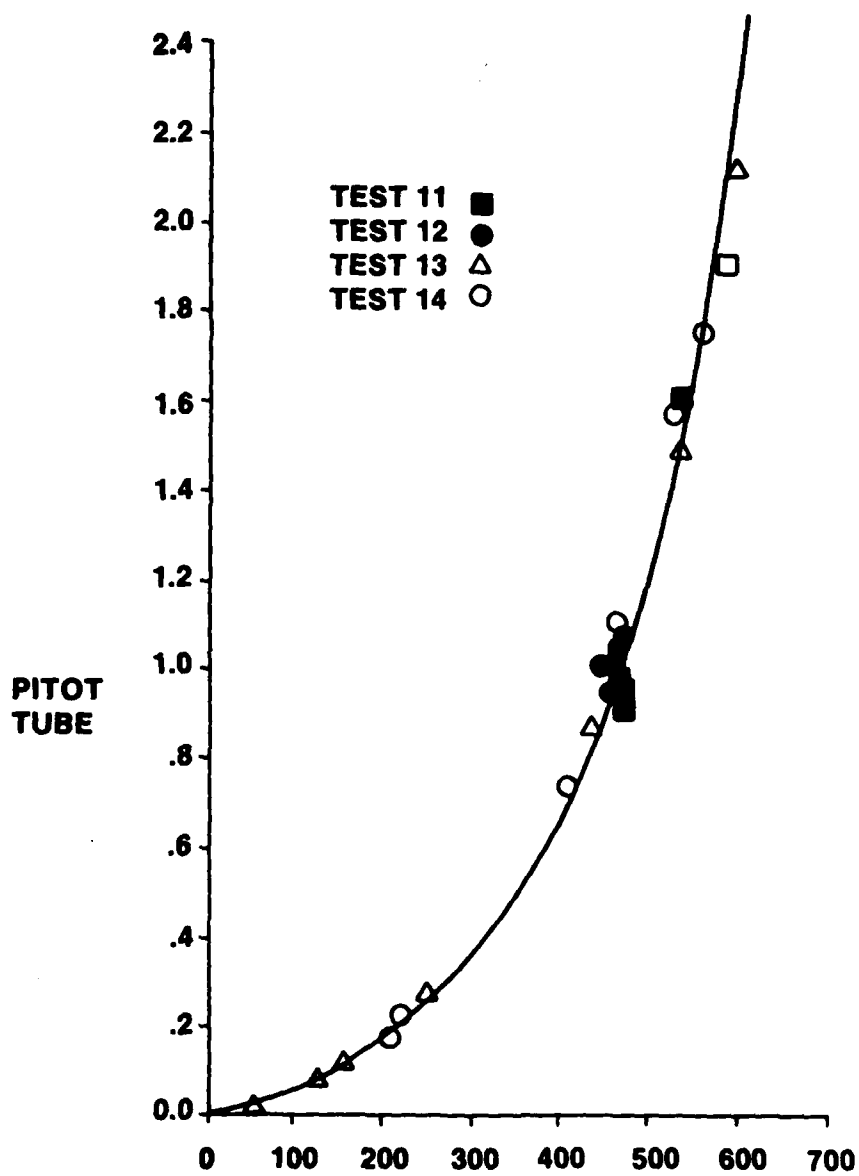


Figure 26. Pitot tube versus Hz for test series 11, 12, 13, 14.

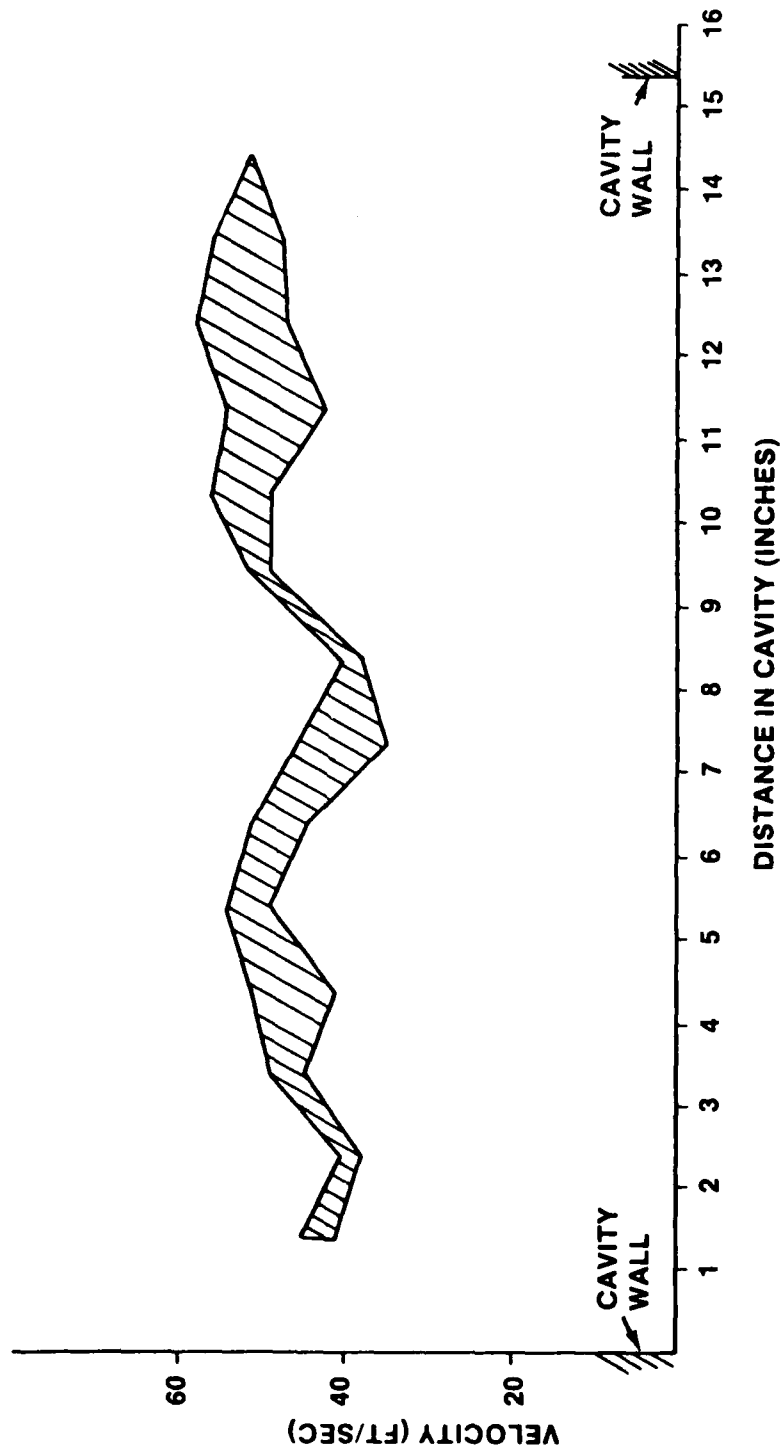


Figure 27. Velocity profile across cavity for test series 22.

Disturbances of the system must be considered. Flowing gases through the cavity, laser pulses, or electrical sparks in the cavity are all capable of causing disturbances. After the disturbance another interferogram is taken.

The shift in the interferometric lenses of the two cases, before and after the pulse, is a measure of the change in gas density. The change in gas density is due to the sum of changes along the light path, which happens to be the cavity length. The frequency of the interferogram light is not always the same as the laser light in the laser cavity.

The uniformity of the laser intensity which is put out in a laser cavity is partially dependent on the uniformity of gas density in the cavity while the laser light is being produced. Gas uniformity within the cavity is extremely important when working with high energy lasers. It is that deviation from uniformity which is measured.

Interferograms are a way of measuring the gas uniformity within the laser cavity. The photograph provides a two-dimensional map of the gas density at one point in time.

The computer programs employed can be divided into three sections: the digitizing and storing of data; the analysis of the interferometric data, which gives the gas density variations and quality factors; and further analysis of the laser system using the gas density values.

Photographs of interference lines, both a standard and an experimental, are used as the basis in determining the amount of interference that is caused by a disturbing system.

These photographs, along with other hard and software, are used to determine variables in the system. These variables can be computed by hand but, because it is such a long and tedious job, a computer program is employed. The program used is a combination of many programs and subroutines arranged by Dr. Arthur H. Werkheiser.

Using the Scriptographics tablet and cursor, a digitized interferogram can be acquired. This is where the computer gets the data to work with in its program.

The computer takes x-y coordinates it receives from the digitized interferogram and a two-dimensional plot of the data is generated.

Comparing the two digitized interferograms the computer can find the line shifts and from there calculate gas density changes.

The computer now takes the data it generated and applies a five-point co-location polynomial to calculate a smoothed interferograph line. It then plots into the smoothed data and determines a tilt plane to be subtracted out which will minimize the rms sum of z values. (z is the percent density change computed).

The program computes the Strehl ratio and the beam quality factor. It then prints this information on the screen along with the tilt plane parameters. This is the end of the computer's analysis.

The following photographs or interferograms (*Figure 28*) are essential to the computer. Using the Scriptographics tablet and cursor the interferogram is digitized. Digitizing is a method of storing the x-y coordinates, which makes up the interference lines, into the computer's memory banks. Because of the way the program reads the x-y coordinates, the lines of the interferogram must be read off horizontally. Vertical interference lines must be turned around making them appear horizontal. After the interferogram has been digitized the photograph is no longer needed except for reference.

To digitize the photograph, the four corner points describing the area are given to the computer by the cursor. Now that the area is defined, the interference lines can be given to the computer by way of the cursor.

After the information has been stored, the computer is ready to carry out further analysis.

The work done by the computer on these interferograms goes only as far as the digitizing step.

6. TRIAL TEST SERIES OF THE CLOSED CYCLE CIRCULATOR (CCC) SYSTEMS AND THEIR PRELIMINARY RESULTS

Following the acceptance test run directed by Rocketdyne, Division of Rockwell International which resulted in a month-long delay due to major repair of the compressor, the CCC system became operational in the first of June, 1979. The CCC system was operated for 31 trial test series without the pentane heat exchanger in operation because of the lack of safety provisions approved by the Safety Office. On account of this deficiency, the CCC system was not able to attain the specified temperature level at the cavity throughout the test runs. A continued effort has been undertaken to make the pentane heat exchanger operational by installing two pentane detectors and one oxygen detector in the building area where the CCC system is installed as well as requesting installations of a ventilation fan and a double-door in

REFERENCE

DATA



RESULTS: $(\Delta\rho/\rho) = \text{RMS DEVIATION}$
 $= 0.002848$

REFERENCE

DATA



RESULTS: $(\Delta\rho/\rho) = \text{RMS DEVIATION}$
 $= 0.001079$

INPUT DATA

**GAS TEMPERATURE = 300° K; GAS PRESSURE = 760 BAR;
HELIUM FRACTION = 0.500; NITROGEN FRACTION = 0.333; CARBON
DIOXIDE FRACTION = 0.167; PROBE LASER WAVELENGTH = 6940
ANGSTROMS; TEST CHAMBER LENGTH = 45 cm; APPLICATION LASER
WAVELENGTH = 10600 ANGSTROMS.**

Figure 28. Interferograms.

the building outside by the Post Facility Engineer. As soon as all of the safety provisions are completely installed, a series of trial test runs with all components the CCC system operating will be conducted to evaluate the performance characteristics of the CCC system prior to the application of pulsed energy inputs at the cavity.

The trial test series performed to date represent an incomplete evaluation of the CCC system performance from the viewpoint of fluid and thermal characteristics of the recirculating flow of laser gas (N₂; CO₂; He, 2:1:3) mixture due to the absence of the LN₂ cooling and the pentane heat exchanger in operation. Temperatures at the cavity were never lowered below 300°K (27°C), but the pressures were attained at the level of 760 ± 20 Torr during each of all test series as shown in *Figures 29, 30, and 31*. The continuing temperature rises and pressure falls at each of all stations (4,5,6,9,11) in the circulator as shown in figures during the continuous run of the CCC system indicate a definite heat imbalance due to excessive heat input by the compressor and inefficient heat sink at the water heat exchangers. These phenomena can be theoretically approximated by the following differential equation:

$$\frac{dQ - dW}{C_p T} = \frac{dT}{T} - \frac{\gamma - 1}{\gamma} \frac{dP}{P} \quad (14)$$

where Q denotes the heat transfer into the system, W the work extracted from the system, T the static temperature, P the static pressure, and C_p the specific heat under constant pressure, and γ the specific heat ratio. When the combined effect of (dQ - dW) is positive, dT should be positive, meaning a temperature rise where dP is negative, a pressure fall.

In *Figures 32 through 35* temperature and pressure distributions along the circulator loop for various mass flow rates in test series 12 and 13 are presented. Effects of the diverter valve are noted in *Figures 32 and 34* at station 5 where the diverted flow at high temperature bypassing one of the heat exchanger (Hx3) is returning to the inlet of heat exchanger (Hx1). *Figures 33 and 35* depict the pressure fall occurring for the temperature rise in accordance with theoretical relationship represented by Equation 14.

These figures present typical distributions of temperature and pressure throughout the circulator loop of all test series conducted to date.

7. CLEANING AND HANDLING OPERATIONS OF THE CIRCULATOR

In order to assemble and disassemble the circulator components of considerable weight in a larger vertical space, three handling devices were designed and fabricated by PDC Associates

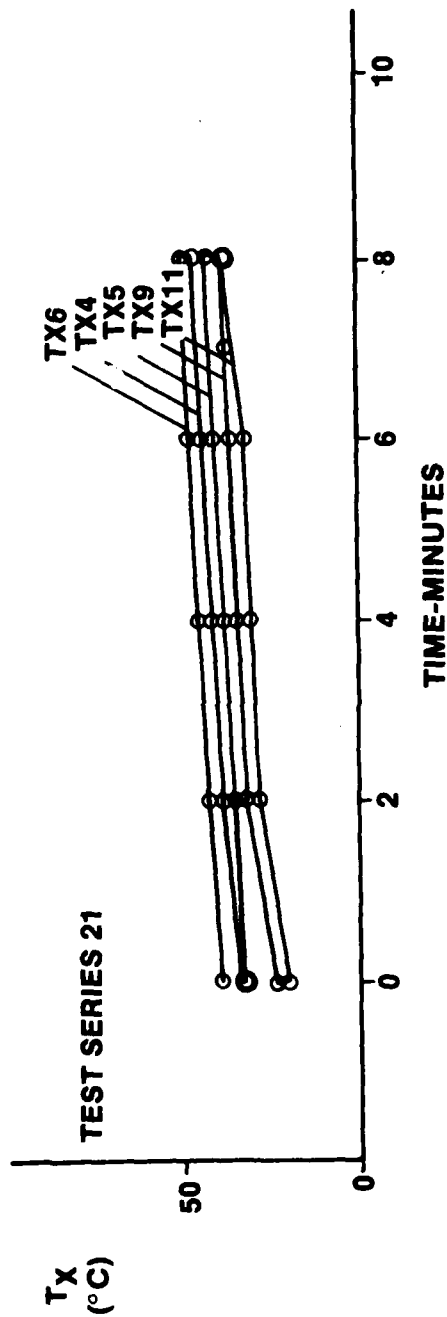
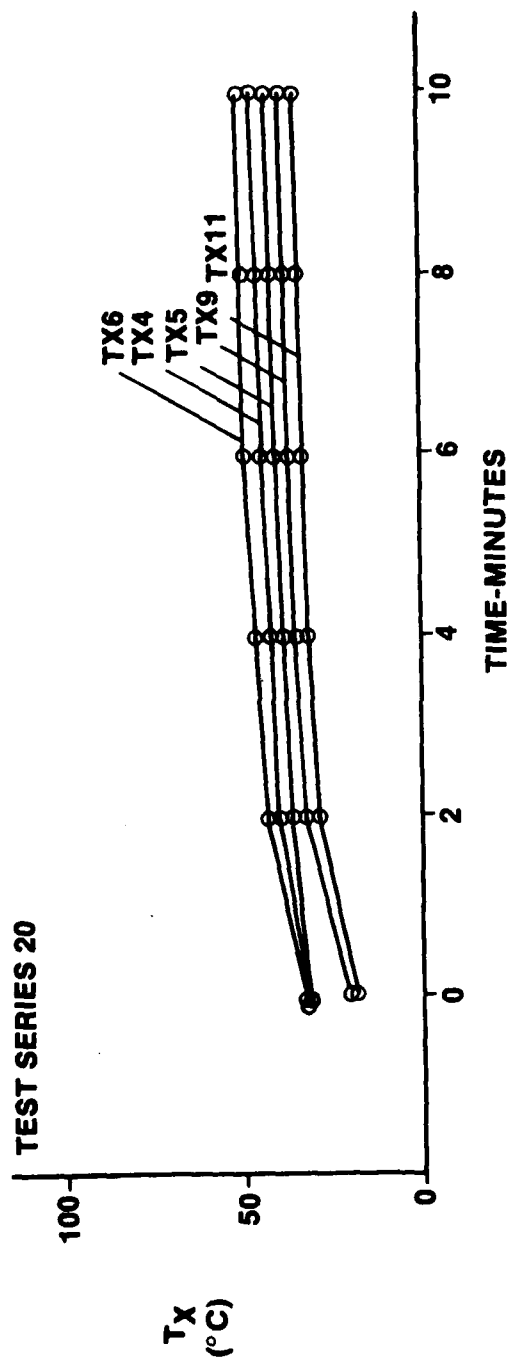


Figure 29. Temperature versus circulator sections for test series 20 and 21.

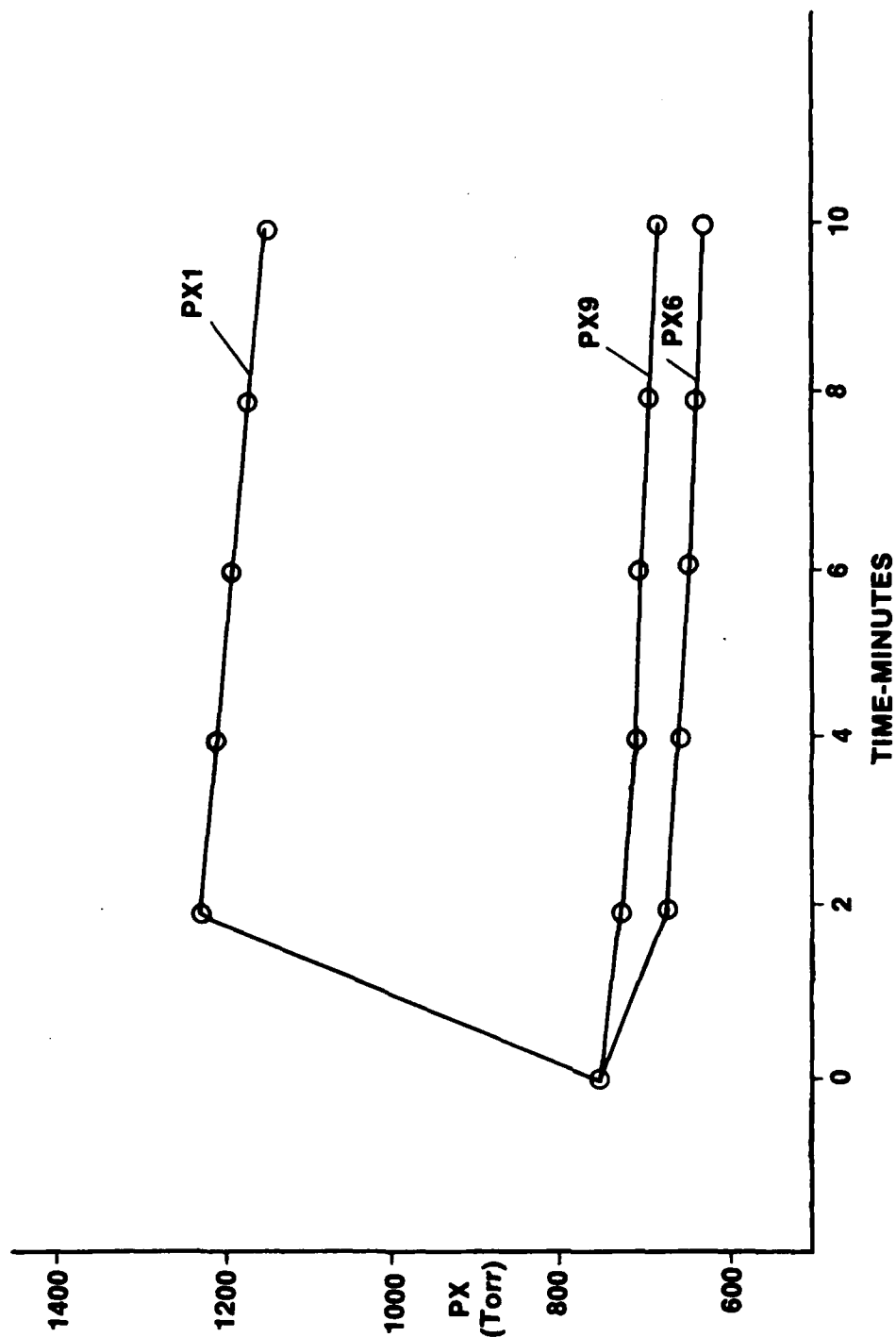


Figure 30. Pressure versus time at circulator sections for test series 20.

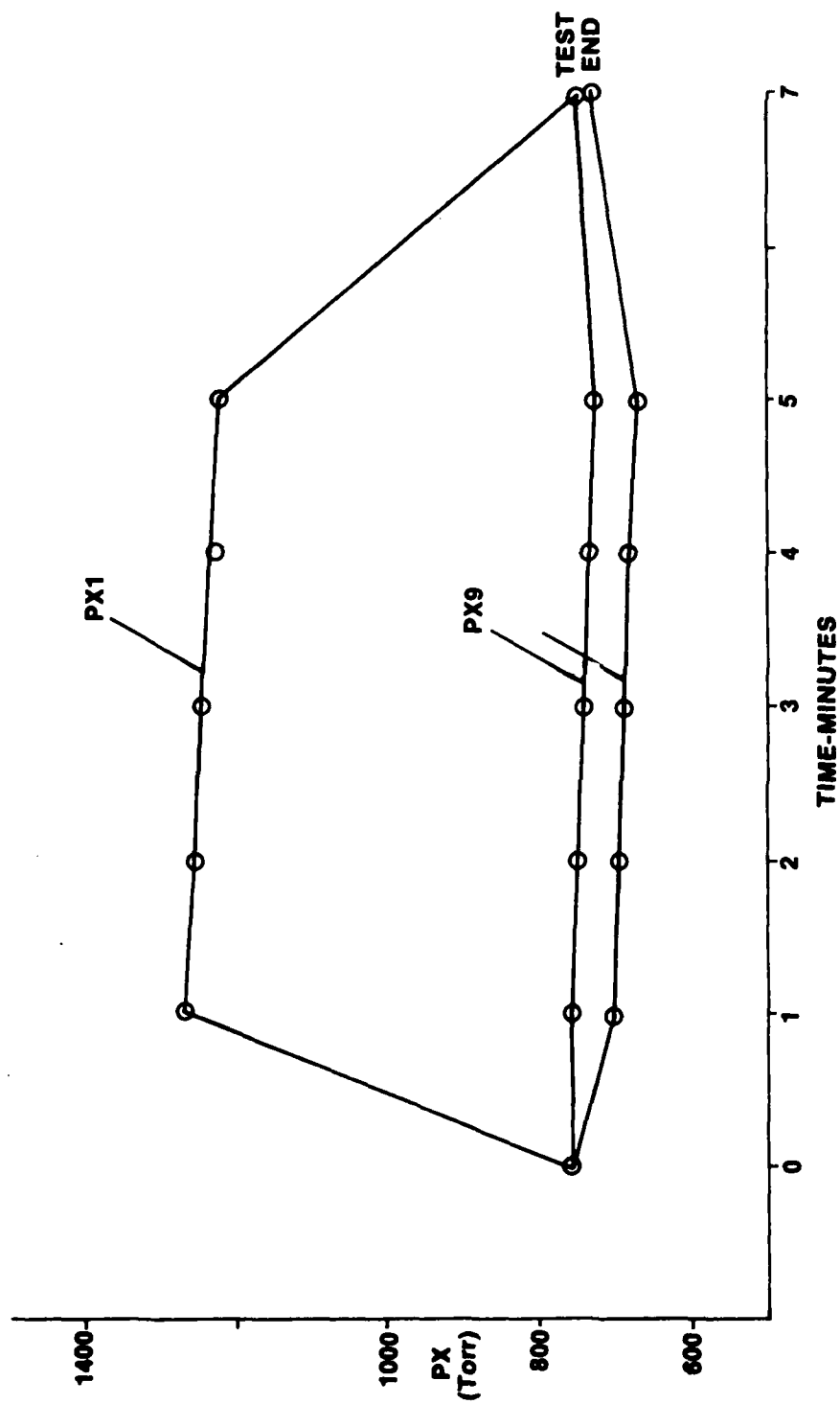


Figure 31. Pressure versus time at circulator sections for test series 24.

<u>MFR</u>	<u>VFR</u>
.8386 lb-m/sec	17.81 ft ³ /sec
.8107 lb-m/sec	17.47 ft ³ /sec
.7792 lb-m/sec	16.97 ft ³ /sec

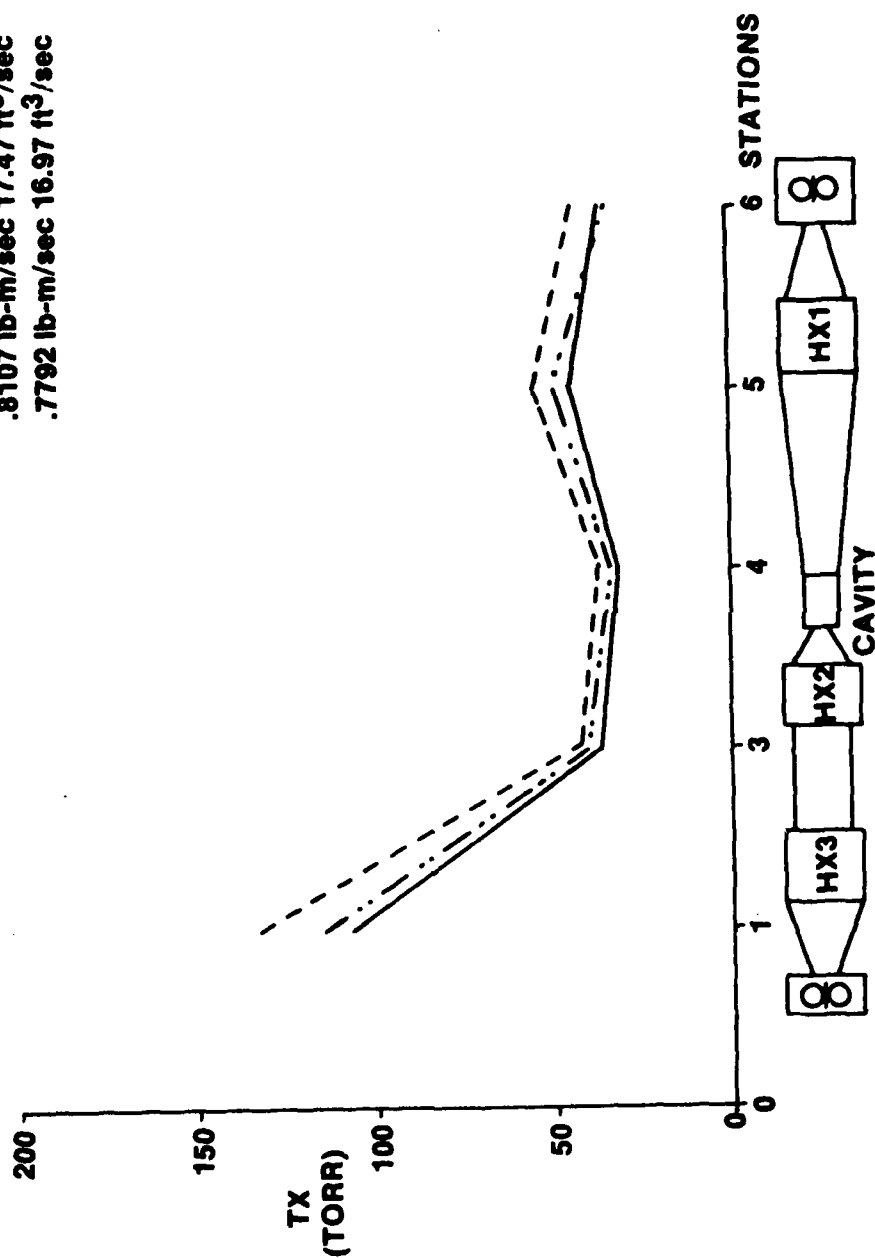


Figure 32. Temperature distribution in circulator sections for various flow rates over a small range in test series 12.

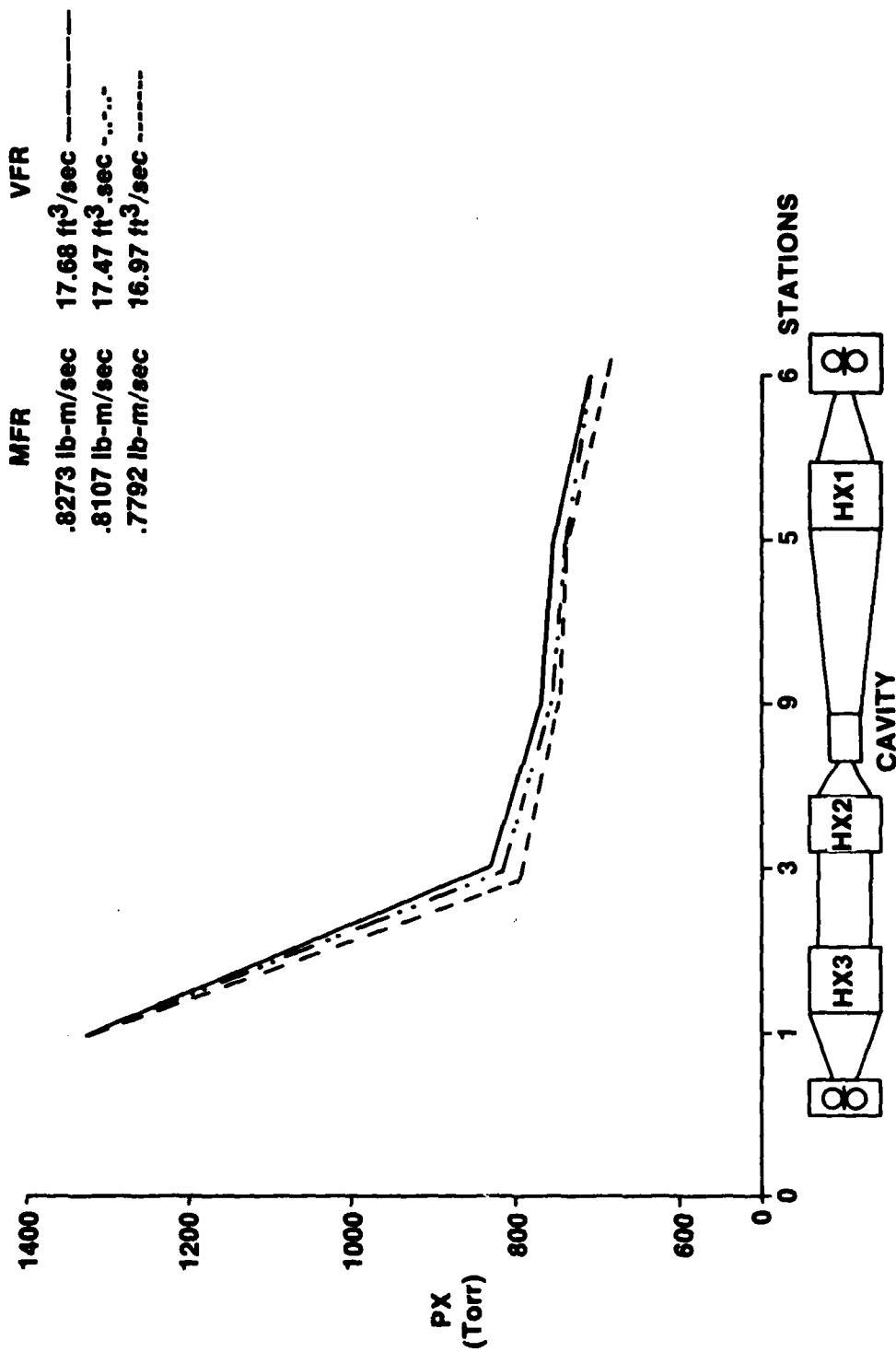


Figure 33. Pressure distribution in circulator sections for various flow rates over a small range in test series 12.

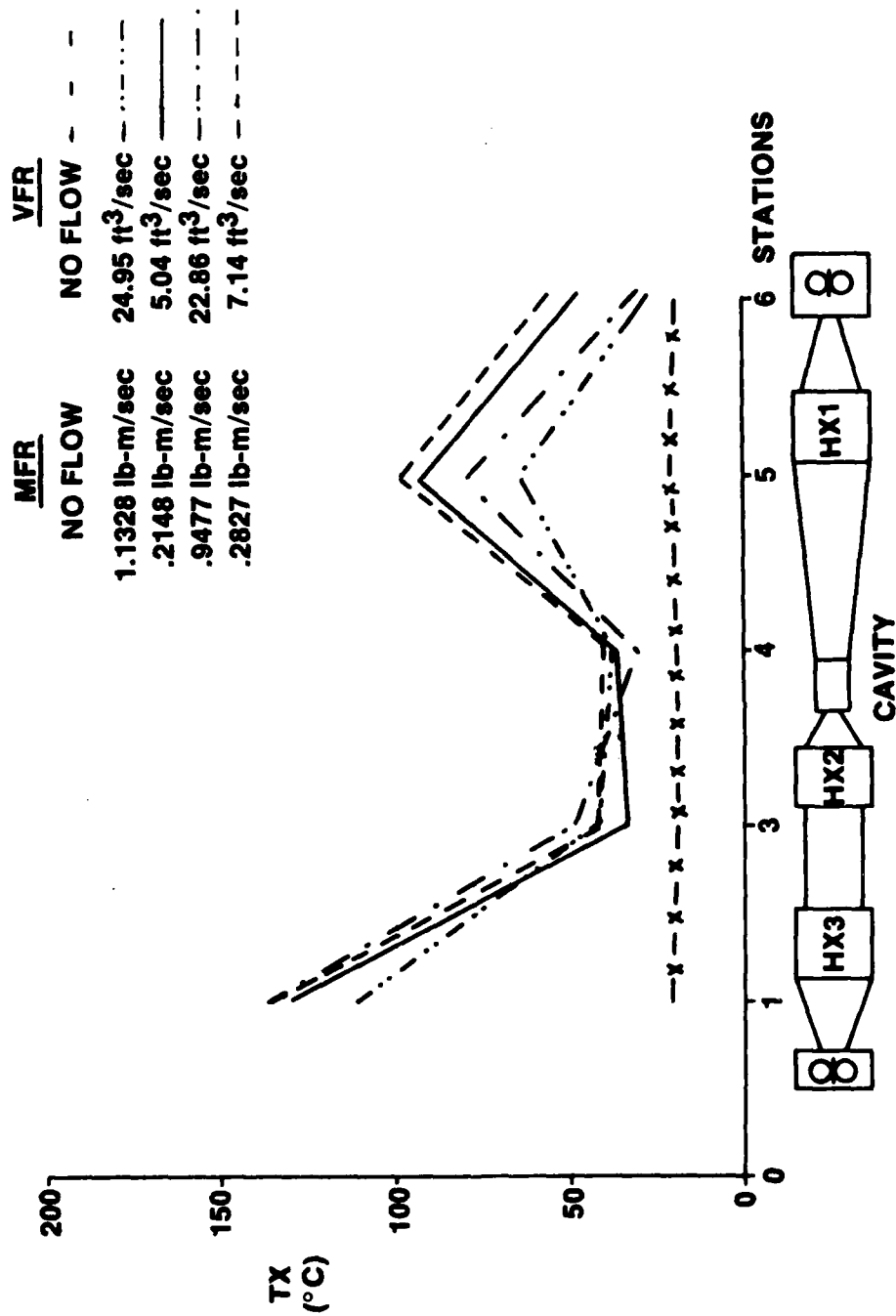


Figure 34. Temperature distribution in circulator sections for various flow rates in test series 13.

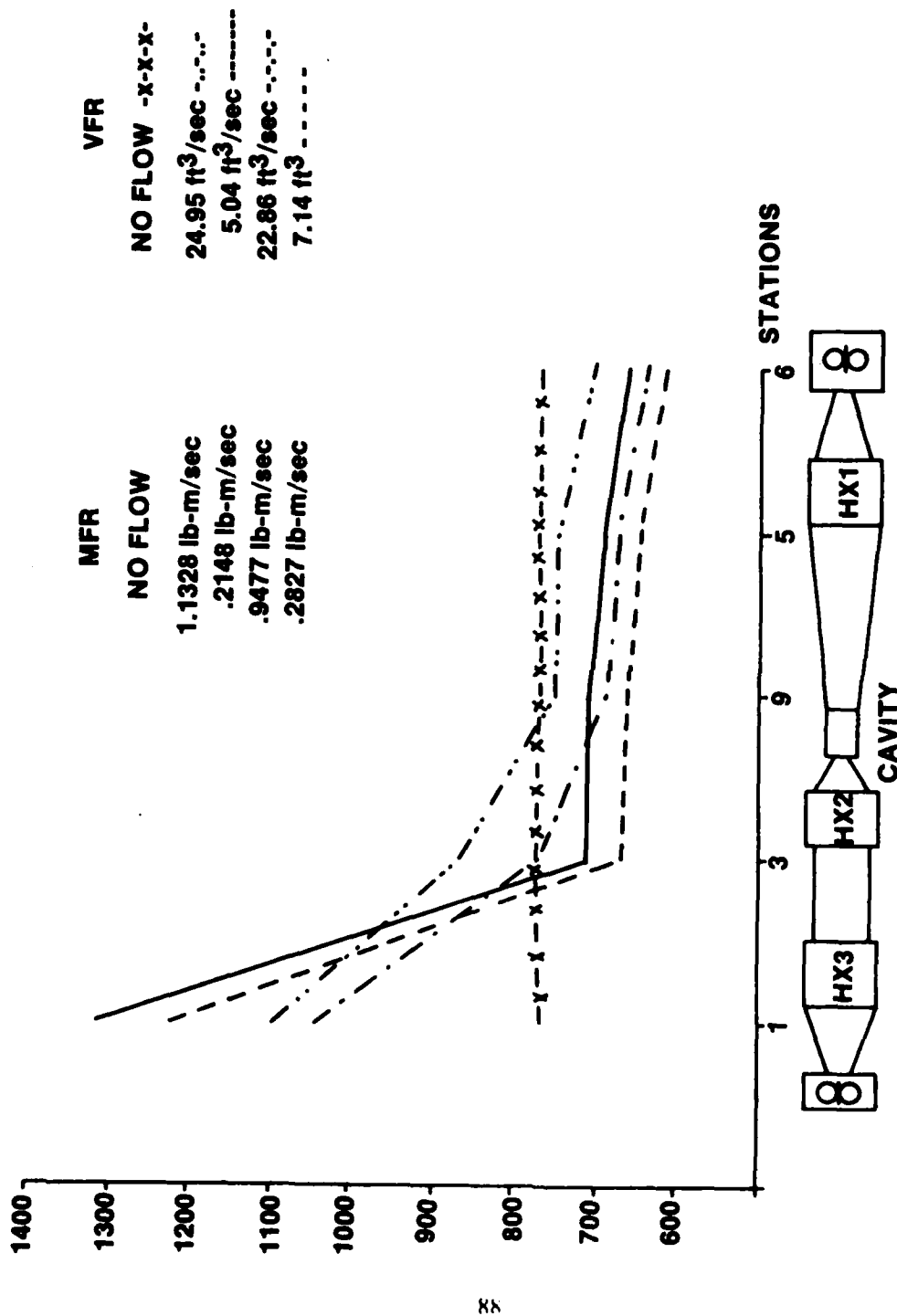


Figure 35. Pressure distribution in circulator sections for various flow rates in test series 13.

of Huntsville as shown in *Figure 36a* through *36f*. *Figures 36a* and *36b* depict views of the support structures for three hanging cradles. Close-up details of the cradle is shown in *C*. A wheeled cart with elevatable top is shown in *D*. *E* and *F* show the fall view and vertical view of the elevatable point support.

The circulator was disassembled after the trial test series, and the interior of all the components was cleaned by a professional purification firm.

Great care was exercised in reassembling the circulator following the component cleaning.



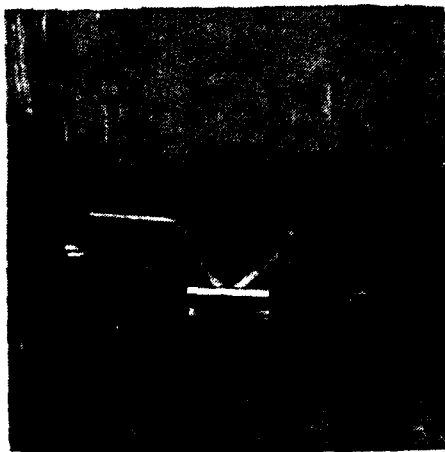
a.



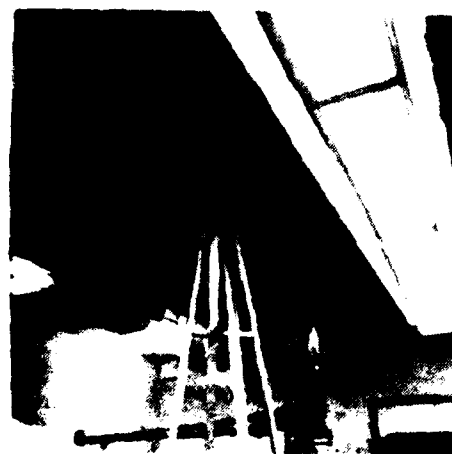
b.



c.



d.



e.



f.

Figure 36. General views of handling devices.

APPENDIX A

**OPERATIONAL, SHUT-DOWN AND MAINTENANCE
PROCEDURES
FOR ARMY CLOSED CYCLE CIRCULATOR (CCC)**

1. OPERATIONAL PROCEDURES

A. CHANGE OF DUCT GAS

1. Close both hand valves to SEAL PRESS, DIFF. GAGE (MOTOR PANEL).
2. Close hand valve to SEAL GAS INLET PRESS. GAGE (MOTOR PANEL).
3. Close hand valve to COMP. DISCHARGE PRESS. (MOTOR PANEL).
4. Disconnect CAVITY PRESSURE (FOXBORO) SENSING LINE.
5. Cap CAVITY PRESSURE TAP.
6. Attach vacuum pump, suction line valve CLOSED.
7. Adjust "K" bottle (laser gas) regulator to 80 psig.
8. Turn PURGE GAS key switch to ON.
9. Open vacuum pump valve and start pump.
10. Close vacuum pump valve when duct reaches a desired Torr.
11. Actuate MAKE-UP GAS switch on console until duct reaches 760 Torr.
12. Repeat steps 9, 10, and 11 several times if it is desired to remove residual amounts of the gas in duct originally.
13. Shut off PURGE GAS.
14. Reconnect CAVITY PRESSURE SENSOR LINE (FOXBORO).
15. Open hand valve to COMP. DISCHARGE PRESS, (MOTOR PANEL).
16. Open hand valve to SEAL GAS INLET PRESS. GAGE (MOTOR PANEL).
17. Open both hand valves to SEAL PRESS. DIFF. GAGE (MOTOR PANEL).

B. COMPRESSOR START

1. Energize compressor control panel.
2. Start compressor oil heatup by pushing compressor start button.
3. Check to see that water is on and flowing through compressor oil cooler (feel line).
4. Throw power switch ON for water pump.
5. Throw power switch ON for pentane pump.
6. Fill water supply tank.
7. Start water pump.
8. Start LN₂ flow to water supply tank.
9. Open both hand valves in PENTANE system.
10. Set PENTANE THROTTLE VALVE control air psig.
11. Start LN₂ flow to PENTANE SYSTEM.
12. Periodically run PENTANE PUMP (about one minute operation every five minutes).

13. Open LN₂ DUCT CHILL flow for short bursts until target temperature is reached.
14. When water supply tank is at and pentane temperature at pump outlet is , perform final duct chillover.
15. Regulate laser gas "K" bottle to .
16. Start make-up flow (if used).
17. Start PENTANE PUMP.
18. Start DUCT LN₂ FLOW.
19. Start COMPRESSOR.

2. SHUT-DOWN PROCEDURES

1. Turn off compressor switch.
2. Wait at least 30 minutes for the system to cool down, then turn all switches off.
3. Turn water and coolant valves off.
4. Turn all instrumentation switches off.

3. MAINTENANCE PROCEDURES

1. Check oil level in the compressor and pressure gages.
2. Check all possible leaks of gas and coolants.
3. Check control switches.

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ARMY MISSILE COMMAND REDSTONE ARSENAL AL HIGH ENER6--ETC F/6 14/2
MID-TERM PROGRESS REPORT ON THE DEVELOPMENT OF ARMY CLOSED CYCL--ETC(U)
SEP 79 M W COLE, C C SHIH
DRCPM-HEL-79-5

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APPENDIX B

FIRST AID PROCEDURES FOR INCLUSION IN THE STANDARD OPERATING PROCEDURES FOR ARMY CLOSED CYCLE CIRCULATOR (CCC)

1. FIRST AID PROCEDURES FOR ELECTRICAL SHOCK VICTIMS

Before touching a victim of electric shock, the circuit should be deenergized or the victim freed from the live conductor by using some suitable nonconductive object, such as a rope, dry wooden stick, or insulated pole. Artificial resuscitation procedures appropriate to the victim's condition shall be started immediately.

The following abbreviated instructions are provided for reference purposes:

A. IF A PERSON HAS STOPPED BREATHING, or his HEART HAS STOPPED BEATING, emergency first aid procedures should be started at once. IF A PERSON IS NOT BREATHING do the following:

1. Place victim on his back. Place on a firm surface such as the floor or ground, not on a bed or sofa.
2. Tilt head straight back. Extend the neck up as far as possible. (This will automatically keep the tongue out of the airway.)
3. Open your mouth wide and place it tightly over the victim's mouth. At the same time, pinch the victim's nostrils shut, or close the nostrils with your cheek, or close the victim's mouth and place your mouth over his nose.
4. Blow into the victim's mouth, or nose, with a smooth steady action until the victim's chest is seen to rise.
5. Remove mouth. Allow the victim to exhale passively and watch the victim's chest fall.
6. Repeat. This cycle should be continued at the rate of one breath each 5 seconds.

NOTE: If you are not getting air exchange, quickly recheck position of head and adequacy of seal around the mouth. If attempts to ventilate are still unsuccessful, sweep fingers through mouth and into throat to remove any foreign bodies. If the rescuer is unable to dislodge the foreign body, turn the victim on his side and give several sharp blows between the shoulder blades to jar it free. After four quick breaths, stop and determine if heart is beating by gently feeling the carotid pulse. If the heart is beating, return to the mouth-to-mouth resuscitation and continue until breathing starts or until a physician tells you to stop.

B. IF THE CAROTID PULSE IS ABSENT OR QUESTIONABLE, start artificial circulation by external cardiac compression.

- 1. Place the heel of one hand on the lower one half of the breastbone and the other hand on top of the first.**
- 2. Thrust downward from your shoulders with enough force to depress the breastbone about 1 1/2 to 2 inches.**
- 3. Relax immediately after each downstroke to permit natural expansion of the chest.**
- 4. Repeat at the rate of about one per second. The compressions must be regular, smooth, and uninterrupted. If you are alone with the victim you must alternate mouth-to-mouth breathing with external cardiac compression at the ratio of about 2 to 15 (two breaths, then 15 heart compressions). If you have help, the ratio of five compressions to one inflation; therefore, after five heart compressions, CALL FOR HELP. Continue one or both of the above while the victim is being transported to the hospital, or until he revives, or until told to stop by a physician.**
- 5. Once the victim is breathing again treat for physical shock if symptoms are present.**

2. TREATMENT FOR SHOCK

Patient pale, cold, sweaty, pulse rapid and weak. Treat by laying patient down, loosen clothes, keep warm, elevate legs. Keep patient quiet.

3. FIRST AID FOR EYE INJURY FROM LASER ENERGY

First aid should not be attempted for damage produced by laser energy to the eye, therefore, prompt reporting to medical treatment facilities is imperative for known or suspected laser injuries. Report injuries to Occupational Health Section, Building 7110, during regular duty hours; during weekends, holidays and after regular duty hours report to Walk-in Clinic, US Army Hospital, Building 112, for treatment. For ambulance service call 6-6110. Telephone number for Occupational Health Section is 6-3045.

4. FIRST AID FOR EYE INJURY FROM CAUSTIC CHEMICALS

A deluge type eye wash and/or shower shall be provided in a readily accessible location. Personnel are to flush the eye(s) for approximately 15 to 20 minutes and then report promptly to medical treatment facilities.

5. FIRST AID FOR SKIN CONTACT WITH CAUSTIC CHEMICALS

Immediately flush the skin with large quantities of water. Report to medical treatment facility for medical care.

6. FIRST AID FOR AIRBORNE EXPOSURE TO ASPHYXIANTS (CRYOGENICS, CARBON MONOXIDE, ETC.)

Remove the individual from the contaminated environment as quickly as possible. The rescuers must use a buddy system and be provided with adequate self-contained breathing apparatus in a contaminated atmosphere.

If the person has stopped breathing, begin mouth-to-mouth ventilation. Quickly check to see if heart is beating; if carotid pulse is absent, begin external cardiac compression. Continue CPR measures until relieved by trained medical personnel.

7. FIRST AID FOR BURNS

Cover and keep clean. Treat for physical shock if necessary.

8. FIRST AID FOR CRYOGENIC CAUSED FROSTBITE

Cover affected area and keep clean. Prohibit smoking. If the lower extremity is involved, treat as a litter patient with the part level or slightly elevated. Have patient transported to a medical facility for emergency treatment.

APPENDIX C

COMPUTER PROGRAM FOR HOT WIRE PROBE CALIBRATION AND LINEARIZATION

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```

0001      FTN,L
0002      PROGRAM PLOT7(), 1 AUG 79
0003      DIMENSION POWER (50), FLOW (50), CALFL(50),
          R(13), A(8.8), S(7).
0004      &WEIGHT (50)
0005      DIMENSION COEFF(5), ERROR(21), X52(8,8)
0006      DIMENSION IPAR(5), IB(5)
0007      DIMENSION X(50), Y(50), NPK(3), MAT(18,19),
          WORK(1), IHLD(1)
0008      REAL MAT
0009      DIMENSION XCAL(23)
0010      DATA XCAL/0.,.75,3.,6.,9.,12.,15.,18.,21.,24.,27.,30.,39.,45.,
0011      &51.,60.,66.,75.,90.,105.,120.,135.,150./
0012      CALL RMPAR(IPAR)
0013      LUI=IPAR(1)
0014      IF(LUI.EQ.0)LUI=1
0015      LUO=IPAR(2)
0016      IF(LUO.EQ.0)LUO=6
0017      LUR=IPAR(3)
0018      IR(LUR.EQ.0)LUR=5
0019      IF(IPAR(5).EQ.1) CALL PLTLU(14)
0020      IF(IPAR(5).EQ.1) CALL SFACT (9.,6.5)
0021      IF(IPAR(5).EQ.1) CALL LLEFT
0022      IF(IPAR(5).EQ.1) CALL PLOT (.5.,5.,-3)
0023      IP=3
0024      CALL TODAY(IB(2))
0025      IB=22
0026      PS=.03611
0027      R=82.76
0028      CK=1.48
0029      ORDER = 4
0030      WRITE(LUI, 1045)
0031      1045  FORMAT(" ENTER PROBE  ")
0032      READ(LUR,*)NP
0033      WRITE (LUO,1048)(IB(KK),KK=2, 12),NP
0034      1048  FORMAT("      SPLINE      PROGRAM",6X, 11A2.
0035      &/" PROBE      ", 12,/)
0036      WRITE(LUI,1055)

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0037      1055  FORMAT(" ENTER P(TORR)")
0038      READ(LUR,*)P
0039      WRITE(LUO,1066)P
0040      1066  FORMAT(" P(TORR)=  ",F7.3,/)
0041      010   DO I,1=1,50
0042      IF(IPAR(4).EQ.0)GOTO 1097
0043      READ(LUR,*)FLOW(I),POWER(I)
0044      IF(FLOW(I).EQ.77.)GOTO 1099
0045      GOTO 1098
0046      1097  READ(LUR,*)PRESS, TEMP, POWER(I)
0047      IF(PRESS.EQ.77.)GOTO 1099
0048      PSI=PRESS*PS
0049      IF(PRESS.EQ.0.)FLOW(I)=0.
0050      IF(PRESS.EQ.0.)GOTO 1098

0051      FLOW(I)=SQRT((2.0*CK*R*32.2*(459.6+TEMP)/(CK-1.0))*
      (1.0-(P*14.7
0052      &/760.0/(PSI+(P*14.7/760.0)))**((1.0-1.0/CK)))
0053      1098  CONTINUE
0054      XP=FLOW(I)*.04
0055      X(I)=FLOW(I)
0056      YP=(POWER(I)-2.0)*3.
0057      Y(I)=POWER(I)
0058      IF(IPAR(5).EQ.1) CALL PLOT(XP,YP,IP)
0059      IP=2
0060      IF(IPAR(5).EQ.1) WRITE(LUO,1010)FLOW(I), POWER (I)
0061      1010  FORMAT(2X,F12.5,F12.5)
0062      1     CONTINUE
0063      1099  CONTINUE
0064      IF(IPAR(5).EQ.1) PAUSE 0001
0065      N=I-1
0066      NPK(1)=7
0067      NPK(2)=7
0068      NPK(3)=N-13
0069      NX=3
0070      NNX=18
0071      CALL SPLIN(X,Y,NPK,NX,MAT,NNX,WORK, IHLD,E)
0072      IF(E,NE.0.)WRITE(LUO,1030)E

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0073      1030  FORMAT(" ERROR, E=", F6.2)
0074          DO 1011 I=1, 12
0075      1011  IF(IPAR(5).EQ.1) WRITE (LUO,1012)I, MAT(1,I)
0076      1012  FORMAT(2X,12,E12.5)
0077          IP=3
0078          DO 1007 I=1,23
0079          XV=XCAL(I)
0080          FLOW(I)=XV
0081          CALL VALSP(XV,X,Y,MAT,NNX,YV)
0082          XP=XV*.04
0083          YP=(YV-2.)*3.
0084          POWER(I)=YV
0085          IF(IPAR(5).EQ.1) CALL PLOT (XP,YP,IP)
0086          IP=2
0087      1007  IF(IPAR(5).EQ.1) WRITE(LUO,1008)I,XV,YV
0088      1008  FORMAT(2X,12,F12.5,F12.5)
0089          NUMBER=23
0090          ZEROE=POWER(1)
0091          ZEROF=FLOW(1)
0092          DO 142 I=1,NUMBER
0093          FLOW(I)=FLOW(I)-ZEROF
0094      142  POWER(I)=POWER(I)-ZEROE
0095          WEIGHT(1)=100.
0096          WEIGHT(2)=80.
0097          WEIGHT(3)=60.
0098          WEIGHT(4)=40.
0099          WEIGHT(5)=20.
0100          WEIGHT(6)=10.
0101          NUM1=NUMBER-1
0102          DO 2, I=7,NUM1
0103      2    WEIGHT(I)=1
0104          WEIGHT(NUMBER)=100.
0105          DO 3, I=1,3
0106      3    R(I)=0
0107          DO 4, I=1,2
0108      4    S(I)=0.
0109          ZI=0.
0110          DO 5, I=1, NUMBER

```

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0111      R(1)=R(1) + WEIGHT(1)
0112      R(2)=R(2) + WEIGHT(1)*POWER(1)
0113      R(3)=R(3) + WEIGHT(1)*POWER*(1)**2
0114      S(1)=S(1) + WEIGHT(1)*FLOW(1)
0115      5  S(2)=S(2) + WEIGHT(1)*POWER(1)*FLOW(1)
0116      NI=1
0117      22 L=NI+1
0118      K1=L+1
0119      DO 7, I=1,L
0120      DO 8, J=1,L
0121      I2 = J-1+1
0122      8  A(I,J)=R(I2)
0123      7  A(I,K1) =S(I)
0124      DO 9, I=1,L
0125      A(K1,I)=-1.
0126      K2=I+1
0127      DO 10 J=K2,K1
0128      10 A(K1,J)=0.
0129      11 C=1./A(1,I)
0130      DO 13, I1=2, K1
0131      DO 14 J=K2,K1,I
0132      14 A(I1,J)=A(I1,J)-A(I1,I)*A(1,J)*C
0133      13 CONTINUE
0134      DO 30 I1 =1, L
0135      DO 31 J=K2, K1
0136      31 A(I1,J)=A(I1+1,J)
0137      30 CONTINUE
0138      9  CONTINUE
0139      DO 141, I=1,L
0140      141 X52(1,K1-2)=A(1,K1)
0141      IF(N1-ORDER)17,23,23
0142      17 NI=NI+1
0143      J=2*NI
0144      R(J) = 0.
0145      R(J+1) = 0.
0146      S(N1+1)=0.
0147      DO 211=1.NUMBER
0148      R(J) = R(J)+(POWER)(1)**(J-1)*WEIGHT(1)

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0149      R(J+1)=R(J+1)+(POWER(I)**J)*WEIGHT(I)
0150      21  S(NI+1)=S(NI+1)+FLOW(I)*POWER(I)**NI)*WEIGHT(I)
0151      GO TO 22
0152      23  MLOOP=ORDER+1
0153      DO 32 I=1,MLOOP
0154      COEFF(I)=A(I,K1)
0155      X52(1,4)=+X52(1,4)*(POWER(NUMBER)**(I-1))
0156      32  CONTINUE
0157      IF(IPAR(5).EQ.1) PAUSE 0002
0158      IP=3
0159      DO 112 JK=2, NUMBER
0160      VP=(POWER)(IK)+ZEROE-2.0)*3.
0161      CALFLO=COEF(I)
0162      DO 113 I=2,5
0163      113  CALFLO=CALFLO+COEFF(I)*POWER(JK)**(I-1)
0164      XP=(CALFLO+ZEROE)*0.4
0165      IF(IPAR(5).EQ.1)CALL PLOT(XP,YP,IP)
0166      IP=2
0167      CALFL(JK)=CALFLO*10./FLOW(NUMBER)
0168      112  ERROR(JK)=(CALFLO-FLOW(JK))*100./FLOW(NUMBER)
0169      SPAN=10./FLOW(NUMBER)
0170      WRITE(LUO,151)
0171      151  FORMAT(/,"  MODEL 1052 OR 1072 LINEARIZER
          COEFFICIENTS")
0172      AA=X52(2,4)*SPAN
0173      BB=X52(3,4)*SPAN
0174      CC=X52(4,4)*SPAN
0175      DD=X52(5,4)*SPAN
0176      WRITE(LUO,1031)AA
0177      WRITE(LUO,1040)BB
0178      WRITE(LUO,1050)CC
0179      WRITE(LUO,1060)DD
0180      1031  FORMAT(" A= ",F12.5)
0181      1040  FORMAT(" B= ",F12.5)
0182      1050  FORMAT(" C= ",F12.5)
0183      1060  FORMAT(" D= ",F12.5,/)
0184      WRITE(LUO,1070)

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0185      1070  FORMAT(" 1 FT/SEC VOLTS NORM V CALC V
                ERR % WT")
0186      DO 35, I=1, NUMBER
0187      FL=FLOW(I)*SPAN
0188      POWI=POWER(I)+ZEROE
0189      WRITE(LUO,121)I, FLOW(I),POWI, FL,CALFL(I),ERROR(I),
                WEIGHT(I)
0190      121  FORMAT(I3,F8.2,4F8.3,F6.1)
0191      C      IF(LUO.EQ.6)WRITE(LUO,1056)
0192      1056  FORMAT("I" )
0193      C      WRITE(LUO,152)
0194      152  FORMAT(/," THESE COEFFICIENTS ARE FOR A TSI
                MODEL ,SERIAL"/
0195      &" CALIBRATED OVER THE RANGE OF 0
                TO IN AT PSIA"/
0196      &" AND DEG . THE BRIDGE OUTPUT WAS VOLTS AT ZERO
                FLOW"/
0197      &" AND VOLTS AT FULL SCALE. THIS DATA SHOULD BE
                USED TO SET"/
0198      &" ZERO AND SPAN.")
0199      1112  DO 1112 JK=2,N
0200      Y2=Y(JK)-Y(1)
0201      CALFLO=COEFF(I)
0202      DO 1113 I=2.5
0203      1113  CALFLO=CALFLO+COEFF(I)*Y2**(I-1)
0204      CALFL(JK)=CALFLO*10./FLOW(NUMBER)
0205      ERROR(JK)=CALFLO-X(JK))*100./FLOW(NUMBER)
0206      WRITE(LUO,1122)JK,X(JK),Y2,CALFL(JK),ERROR(JK)
0207      1122  FORMAT(I3,F8.2,3F8.3)
0208      END
0209      SUBROUTINE VALSP(XV,X,Y,MAT,NNX,YV)
0210      DIMENSION X(I),Y(I),MAT(18,19)
0211      REAL MAT
0212      I=0
0213      IF(XV,GT,X(7))I=1
0214      IF(XV,GT,X(14))I=2
0215      YV=0.
0216      DO 10 J=4,1,-1

```

```
0217 10 YV=MAT(J+4*I,I)+XV*YV
0218 RETURN
0219 END
0220 ENDS
```

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